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MAINTAINABILITY ENGINEERING

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PREPARED FOR:

Rome Air Development Center
Research and Technology Division
Air Force System Command
United States Air Force
Griffiss Air Force Base. New York

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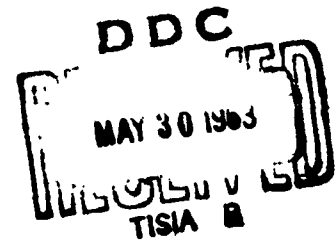
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MAINTAINABILITY TECHNIQUE STUDY

FOREWORD

The objective of this program was to investigate the factors which influence the maintainability of Air Force electronic equipment and further, to identify and measure these factors to provide a quantitative methodology for specifying and predicting the maintainability of new systems and equipment. These objectives were met through the implementation of a five (5) phase program. An extensive field data collection program, necessary because of the lack of basic time-to-repair data, made it possible to identify and measure the primary factors affecting ability to perform maintenance. Analysis of the data and application of statistical techniques resulted in the formulation of a Maintainability Prediction Technique, thus meeting the original program objectives.

The results of this study have already found application in a number of Air Force contracts and are reflected in the measurement and demonstration procedures described in Appendix A of Specification MIL-M-26512B "Maintainability Requirements for Aerospace Systems and Equipment." The results of this study will find greatest application to electronic systems. Further investigation is needed to prove its validity in electromechanical systems.

FRANK D. MAZZOLA, Project Engineer

The maintainability techniques presented in this
report represents the combined effort of the
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ABSTRACT

This report, contained in two volumes, summarizes the final
results achieved in the performance of the Maintainability
Techniques Study sponsored by the Rome Air Development
Center under Contract AF30(602)2057. The broad objective
of this study was the formulation of a maintainability
technology applicable to ground electronic systems.

Volume I, describes the investigations made to (1) identify
factors affecting maintainability, (2) specify maintaina-
bility of a quantitative basis, (3) improve design of ground
electronic equipment, (4) predict maintainability of elec-
tronic systems, and (5) derive trade-offs relating relia-
bility, maintainability, and other system parameters.
Particular emphasis is given to the fifth phase of study
which was devoted to validation of the prediction technique
and the investigation of the Electronic Maintenance
Proficiency Test. The volume is concluded by noting the
current status of maintainability technology and recommending
areas for additional research.

Volume II is a compilation of the analytical techniques
and related maintainability information developed in the
course of the study. Topics treated include: maintenance
theory and classification, systems maintenance engineering,
design guidelines, prediction technique, design review,
demonstration testing, and field data acquisition.
Collectively, this information forms a body of knowledge
useful to the maintainability engineer.

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MAINTAINABILITY ENGINEERING

1. INTRODUCTION

1.1 Purpose of the Report

It is the intent of this document to draw together all useful information and techniques developed in the performance of the Maintainability Techniques study accomplished under contract with the Rome Air Development Center. This information is provided primarily for use by the maintainability engineer who is responsible for meeting specification requirements imposed on system development. Data are provided concerning maintenance specification and compliance demonstration which should be useful to contracting agencies. The general format in the development of the report closely follows the steps taken during system development cycle.

1.2 Requirement for Maintainability Engineering

With the establishment of maintainability as a quantitative specification value, it is necessary that personnel responsible for meeting these requirements be equipped with the necessary analytical tools. As with any technology, maintainability requires methods for measurement, estimating, and evaluation. Unfortunately, not all aspects of maintainability, at this point in time, are definable in numerical terms. Within this area maintainability becomes an art, guided only by qualitative factors. In this report primary emphasis has been placed on the quantitative approach to maintainability; but in certain areas only general guidance can be provided.

1.3 Summary of Contents

A general discussion of the maintenance process and its underlying theory is provided in Section 2. This is coupled with a discussion of appropriate maintenance indices including methods for computation and statistical testing. Section 3 summarizes a typical maintainability program to be employed during the system development cycle. A discussion of the major tasks is provided, including their relation to the development time frame. Section 4 establishes criteria

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for maintainability design, Areas of concern include
maintenance concept, design goals, and design guidelines
necessary to meet maintainability requirements. Section
5 describes the application of the maintainability pre-
diction technique to system design evaluation. The steps
entailed are presented with several examples of the pro-
cess. Section 6 discusses design review procedures which
aid in achieving an optimum balance between maintainability
and other system characteristics. Additionally, methods for
identifying maintainability problem areas within the system
are provided as a means of indicating product improvements.
Section 7 incorporates a maintainability testing procedure
used for system demonstration testing. Such tests are the
current means of determining system compliance with imposed
specifications. Several methods for collecting field
maintenance data are discussed in Section 8. Supplementing
the report are three appendices which respectively present
maintainability checklists, mathematical formulas, and
maintenance data forms.

2. MAINTENANCE THEORY & CLASSIFICATION

2.1 The Maintenance Process

Maintenance is defined as those actions necessary for retaining material in, or restoring it to, a serviceable condition. Maintenance includes determination of condition, servicing, repair, modification, modernization, overhaul, and inspection. Three factors are needed to create a maintenance situation. These include equipment, technical personnel, and support facilities. This statement is true for maintenance as it is performed generally on systems now in use. Systems which incorporate self-test devices diminish, to some degree, the importance and number of technical personnel required for the maintenance processes. Such devices have a tendency to shift manpower requirements rather than reduce total expenditure. Since the test equipment itself must be maintained, some of the expected gains are partially nullified. However, the reduction of system down time through the use of self-test devices may warrant their consideration. The point to be made is that maintenance as accomplished today, and in the forseeable future, will involve hardware, technical personnel, and support facilities.

2.1.1 Man-Machine Relation - Maintenance time obviously is a function of the inherent characteristics of the essential maintenance factors. For the purpose of further discussion, measures of these factors will be identified as design, personnel, and support. To illustrate further consider the representation provided in Figure 2.1, "Man-Machine Interface."

2.1.1.1 One of the fundamental processes of man is that of stimulus, integration or differentiation, and reaction. This process when applied to the machine (design) forms the basis of the maintenance action. On the man-machine interface is presented the environment (support), through which this process must be accomplished. The machine (design) contains such features as built-in test equipment, indicators, and test points which provide stimulus for the man through the environment. Through human

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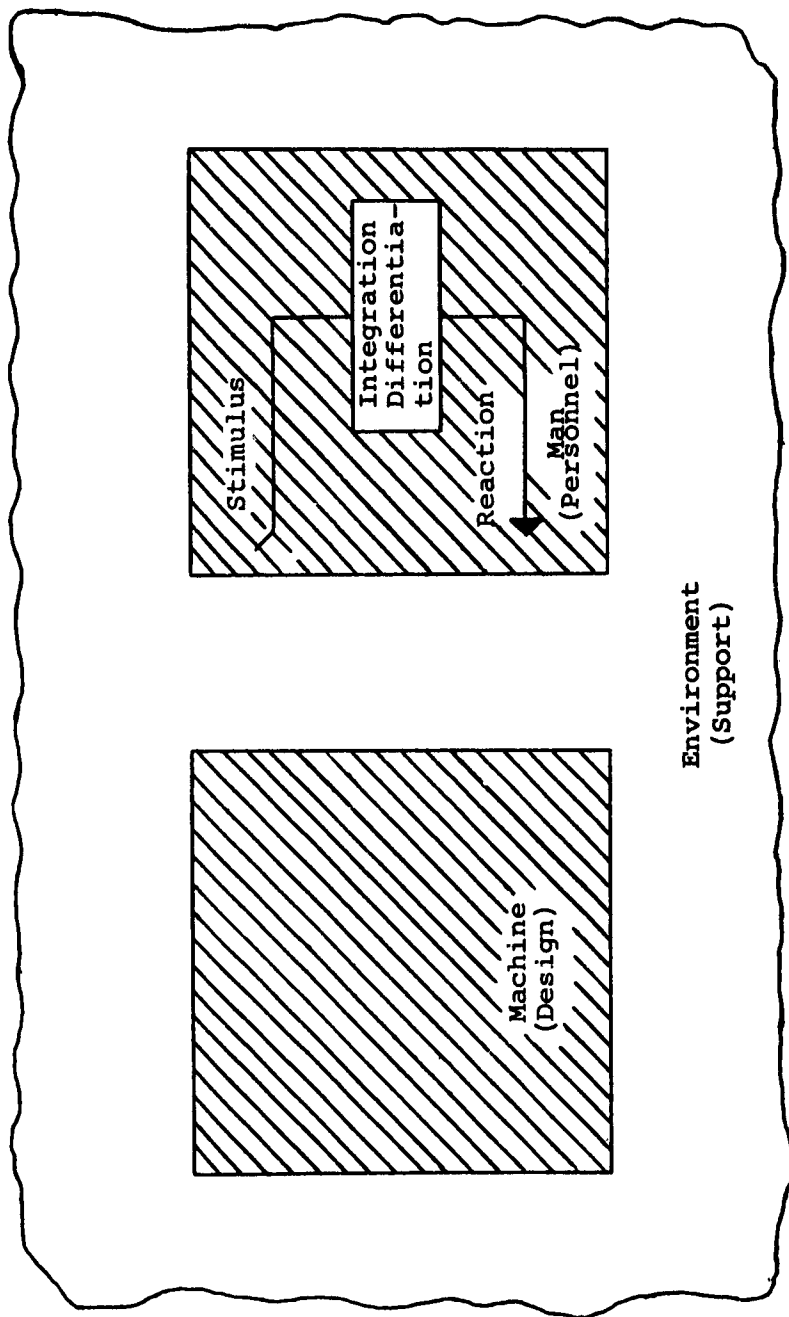
FIGURE 2.1. MAN-MACHINE INTERFACE

capabilities these stimuli are integrated or differen-
tiated and the result is a reaction. These reactions, in
turn, are directed to the machine through the environment.
This process continues until the repair has been effected.
The task, which presents itself, is to determine the
features of the machine (design) which will enhance this
process; the factors of the environment which contribute
to it (support); and finally, the capabilities of the
technician (personnel).

2.1.1.2 Further examination of the factors, design,
personnel, and support is made below:

a. Design - This encompasses all the design features of
   the equipment. It covers the physical aspects of the
   equipment itself, requirements for test equipment and
   tools, training, and personnel skill levels required to
   do maintenance as dictated by design, packaging, test
   points, accessibility, and other factors internal to
   the equipment.

b. Personnel - This includes the skill level of the main-
   tenance men, their attitudes, experience, technical
   proficiency, and other human factors which are usually
   associated with equipment maintenance.

c. Support - This area covers logistics and maintenance
   organization involved in maintaining a system. A
   short breakdown of support would include tools and
   test equipment on hand at a parituclar location, the
   availability of manuals and technical orders associated
   with the equipment, the particular supply problems
   which exist at a site and finally, the general mainten-
   ance organization.

2.1.2 Task Ingredients - Figure 2.2, "Maintainability
Factors," illustrates the interrelation of the three factors
further. Within the triangular representation, the domain
of maintenance is illustrated. Points lying within indicate
the contribution of design, personnel, and support. As an
example, the task at point p is comprised of (a) units of
design, (b) units of personnel and (c) units of support.
Thus, all real maintenance tasks will contain ascribable,
quantities of these three factors and although some of
their aspects can be considered to be independent, a certain
degree of interdependence may be assumed to exist. For
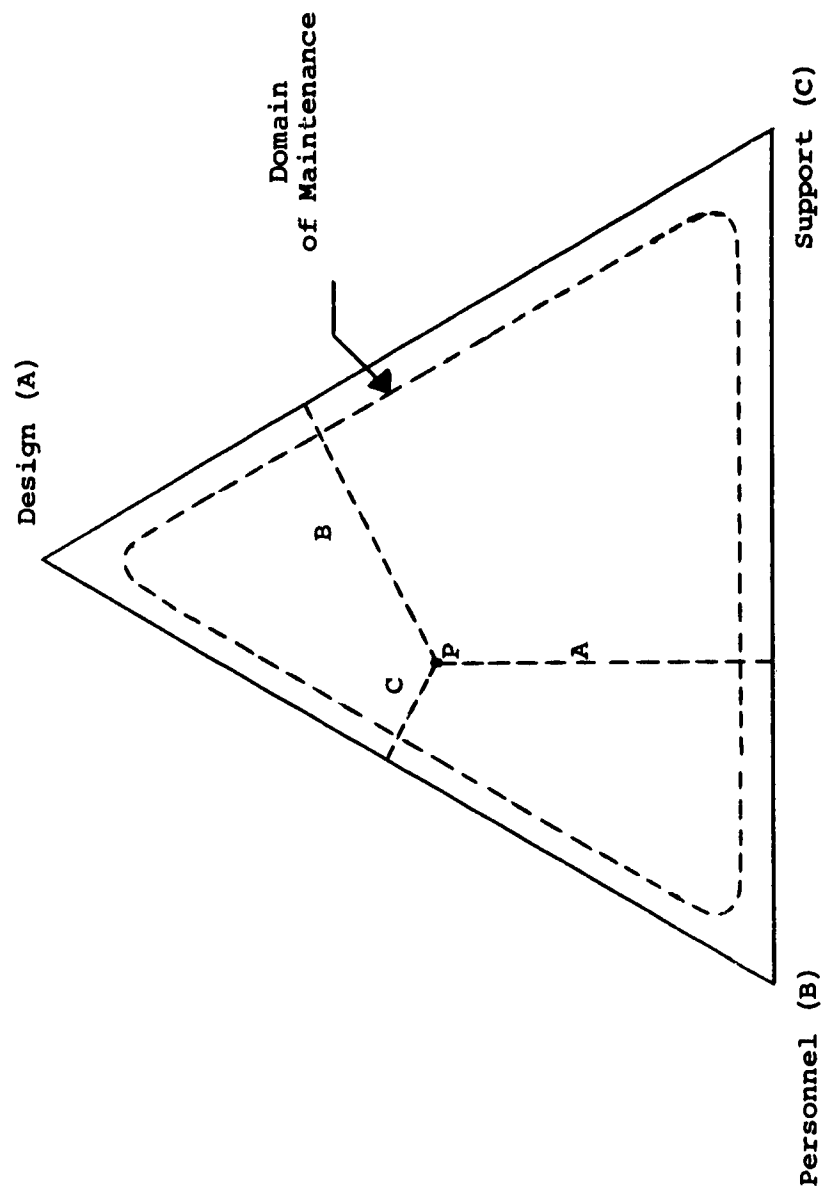
FIGURE 2.2. MAINTAINABILITY FACTORS

example, design will certainly influence support through
the requirements for spares; that is, the use of many non-
standard parts imposes an additional load on the support
structure. Similarly, the complexity of design will re-
quire the use of more highly skilled maintenance personnel.
The lack of highly skilled maintenance personnel dictates
that the design incorporate features to facilitate the
ease of maintenance. Personnel will influence technical
data requirements which is a support item. Support will
influence to some degree both personnel selection and
certain design features.

2.1.3 <u>Task Elements</u> - To secure a better understanding of
the maintenance process it is necessary to learn more of
its structure. Figure 2.3, "Maintenance Flow Diagram,"
presents the five major sequential steps performed during
maintenance. These steps include: (1) recognition that
a malfunction exists, (2) localization of the defect with-
in the system to a particular equipment, (3) diagnosis
within the equipment to a specific defective part or
component, (4) repair or replacement of the faulty item
and (5) checkout and returning the system to service.
Completion of the checkout phase, if conclusive, restores
the equipment to operational status. Complementary to the
steps delineated are actions associated with assembly,
disassembly, cleaning, lubrication, supply, and
administrative activity.

2.1.3.1 Also included in the "Maintenance Flow Diagram" are
two supplementary paths. The first is for those malfunctions
which, either due to their obvious nature or due to
technician's experience, can be isolated immediately.
The maintenance cycle then progresses immediately from the
recognition step to either the diagnosis or repair phase.
On occasion, during the troubleshooting sequence a wrong
assumption may be made, or when an interactive malfunction
is encountered, the technician is required to retrace his
steps and make further analysis before effecting the
repair.

2.1.3.2 The comparative contribution of each time element
is illustrated in Figure 2.4, "Element Contribution of
Maintenance Time." In the figure, the elements have been

FIGURE 2.3. MAINTENANCE FLOW DIAGRAM

Corrective Maintenance

50 ─

45 ─

40 ─

35 ─

30 ─

Percent Contribution

25 ─

20 ─

15 ─

10 ─

5 ─

0 ─

a   b   c   d   e   f   g   h
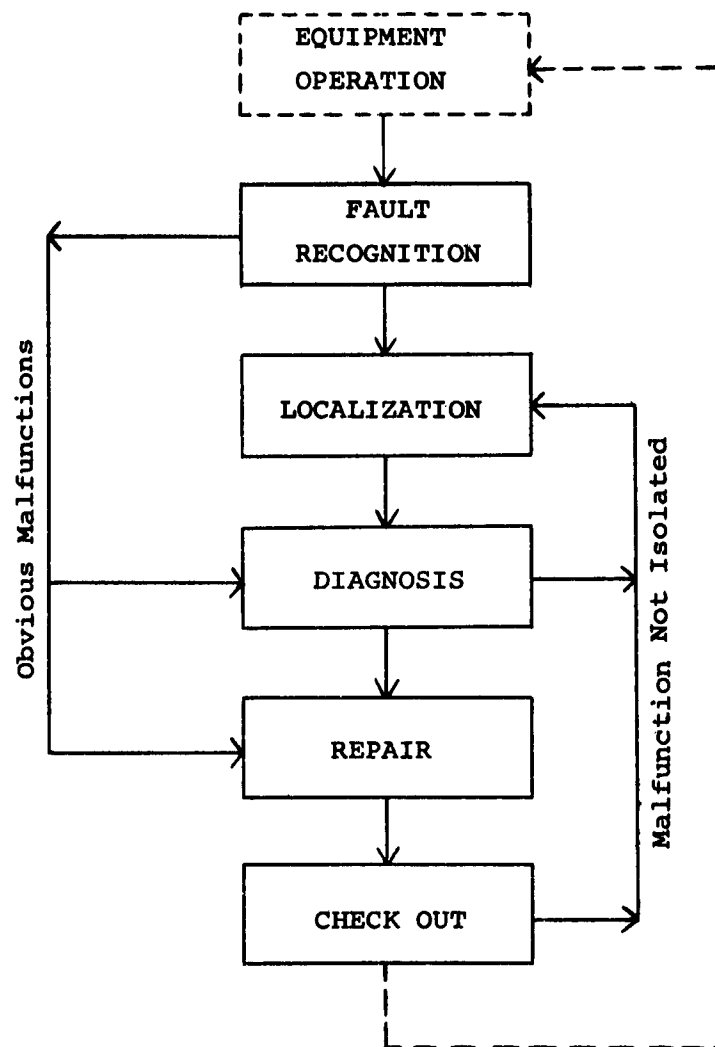
Maintenance Elements
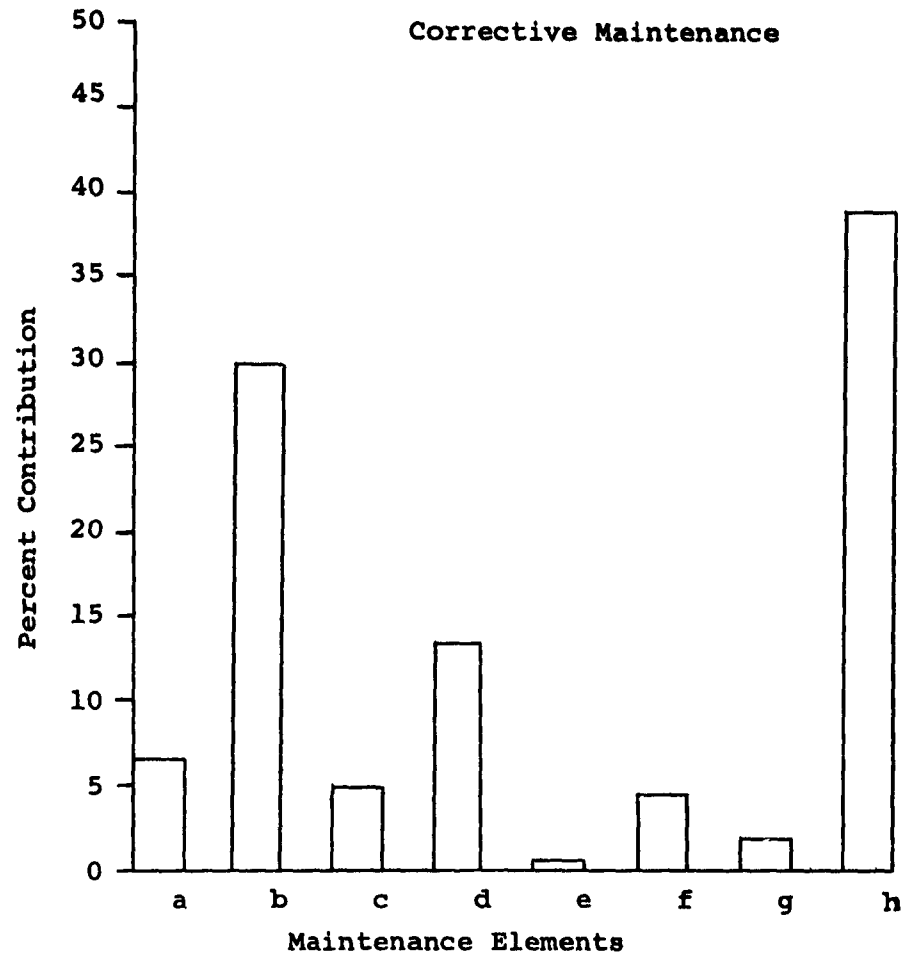
FIGURE 2.4. ELEMENTS OF MAINTENANCE TIME

alphabetically identified and are cross-referenced as follows:

a. Assembly and Disassembly
b. Inspecting, Testing, and Measuring (Diagnosis and Localization)
c. Remove and Replacement (Repair)
d. Checkout
e. Cleaning and Lubrication
f. Securing Materials (Supply)
g. Preparation of Reports ⎫
h. Contingency items   ⎬ Administrative

The percentages shown have been developed from 101 task measurements taken on three different equipments. It is interesting to note the high contribution on contingency items (element h) which does not contribute productively to maintenance accomplishment. Of the productive contributions, element b constitutes the most important item. Data of this type identifies the primary elements which must be considered during maintainability design.

2.2 Maintenance Classification

To specify maintainability it is necessary to determine and define the various types of maintenance activities. Knowledge of the elements constituting a maintenance task will contribute to the ability to relate the affecting factors to maintenance time. Through this examination it will be possible to derive descriptive numerics or indices that will provide a basis for specifying maintainability.

2.2.1 Types of Maintenance - It is recognized that maintenance actions are precipitated by several causes and can occur in different locations. Field maintenance is considered to be the repair activity performed at the equipment site. Total maintenance is composed of preventive and corrective maintenance. These have been defined as:

a. Preventive Maintenance - That maintenance performed to maintain a system or equipment in satisfactory operational condition by providing systematic inspection, detection, and correction of incipient failures before they occur or develop into major failures.

b. <u>Corrective Maintenance</u> - That maintenance performed on a nonscheduled basis to restore equipment to a satisfactory condition by providing correction of a failure which has caused degredation to the equipment below its specified performance.

Adjustments, lubrication, routine check-out, etc are included in the category of preventive maintenance. It should be recognized that these two basic maintenance actions can occur either while the equipment is in or out of service. Thus, it is not only necessary to recognize the type of action, but also the operational status of the equipment as well. Such considerations are important for the development of figures of merit for equipment maintainability.

2.2.1.1 From the above discussion, it has been noted that maintenance can occur at the operational level or higher echelons. Two fundamental types of actions, defined as corrective and preventive, have been cited. Finally, it was noted that the operational status of the equipment must also be considered when discussing maintenance. To provide a clearer picture of the types of maintenance, Figure 2.5, "Classification of Maintenance Tasks," has been prepared. Here the types cited above have been set down and the various possible combinations developed.

2.2.1.2 A total of 8 distinct classifications have been derived. Example: task classification (1) is a corrective maintenance action performed at operation level and requires the system to be down. The removal of a defective system component and its replacement by an operating component is an example of (1). The subsequent repair of the defective component at a location removed from the operating equipment is an example of class (7).

2.2.1.3 Through this matrix it is possible to order the spectrum of maintenance activities so that specifications and indices may be derived that relate to the operating and maintenance environment. It is readily apparent that only those maintenance actions requiring the system to be removed from service affect availability, whereas all maintenance actions affect maintainability as defined here.

		CATEGORIES OF MAINTENANCE							
		1	2	3	4	5	6	7	8
AREA OF PERFORMANCE	Operational Level	X	X	X	X				
	Higher Echelon					X	X	X	X
TYPE OF ACTION	Corrective	X		X		X		X	
	Preventive		X		X		X		X
EQUIPMENT OPERATIONAL STATUS	System Down	X	X			X	X		
	System Operating			X	X			X	X

FIGURE 2.5. CLASSIFICATION OF MAINTENANCE TASKS

2.2.2 <u>Down Time Relations</u> - To illustrate the relation of the various maintenance activities at the operation level to system down time, Figure 2.6, "Down Time Classification," is provided. Beginning with the cause of maintenance, the figure illustrates that it will create either a preventive or corrective maintenance situation. Next the process notes whether or not an equipment failure is present, and, if so, is it to be considered critical. This information then permits the determination of the operational status of the equipment. The final classification made is to assign the resultent maintenance time to one of three categories; i.e. no down time, deferrable down time, and down time. From the equipment operational standpoint maintenance which requires down time is most important. However, from a resource expenditure point of view all maintenance requirements are of concern.

2.3 <u>System Relations</u>

The previous paragraphs of this section have detailed some of the maintainability concepts. To provide a more comprehensive perspective on the relation of maintainability to other system characteristics, a brief discussion of system effectiveness is presented here.

2.3.1 The principal ingredients of system effectiveness are shown in Figure 2.7, "Ingredients of System Effectiveness." Effectiveness may be defined as a measure of customer satisfaction - it implies net worth or value of a product to its user. This value in turn depends upon, (1) the capability of the product, or the degree to which it meets the customer's requirements, and (2) the total cost of the product.

2.3.2 System capability is shown to be a function of performance and dependability. Performance implies the ability to meet specified characteristics such as range, accuracy, stability, power output, etc. Dependability includes reliability, maintainability, availability, and other similar product characteristics important to the customer but not generally specified, as are performance characteristics.

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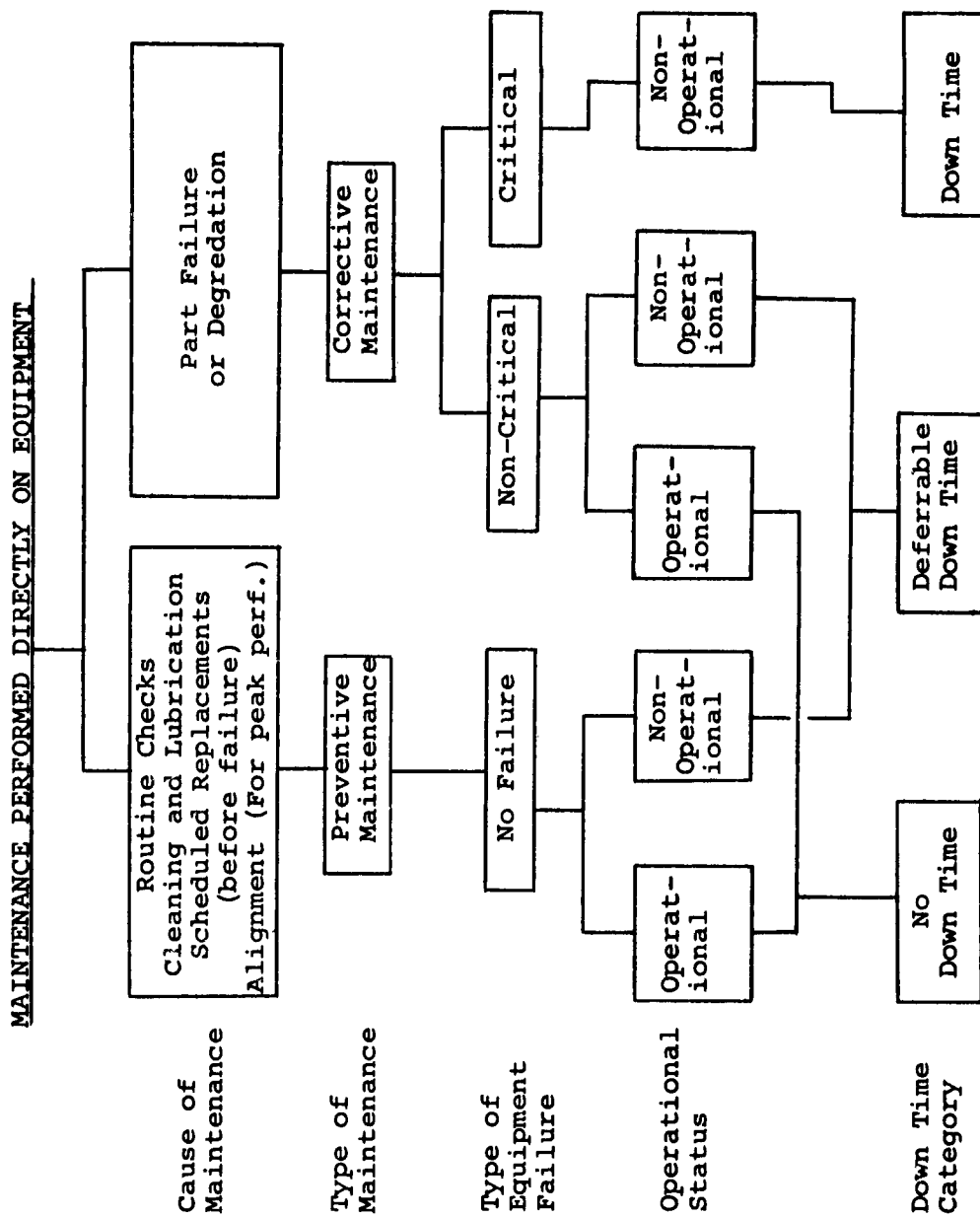
FIGURE 2.6. DOWN TIME CLASSIFICATION
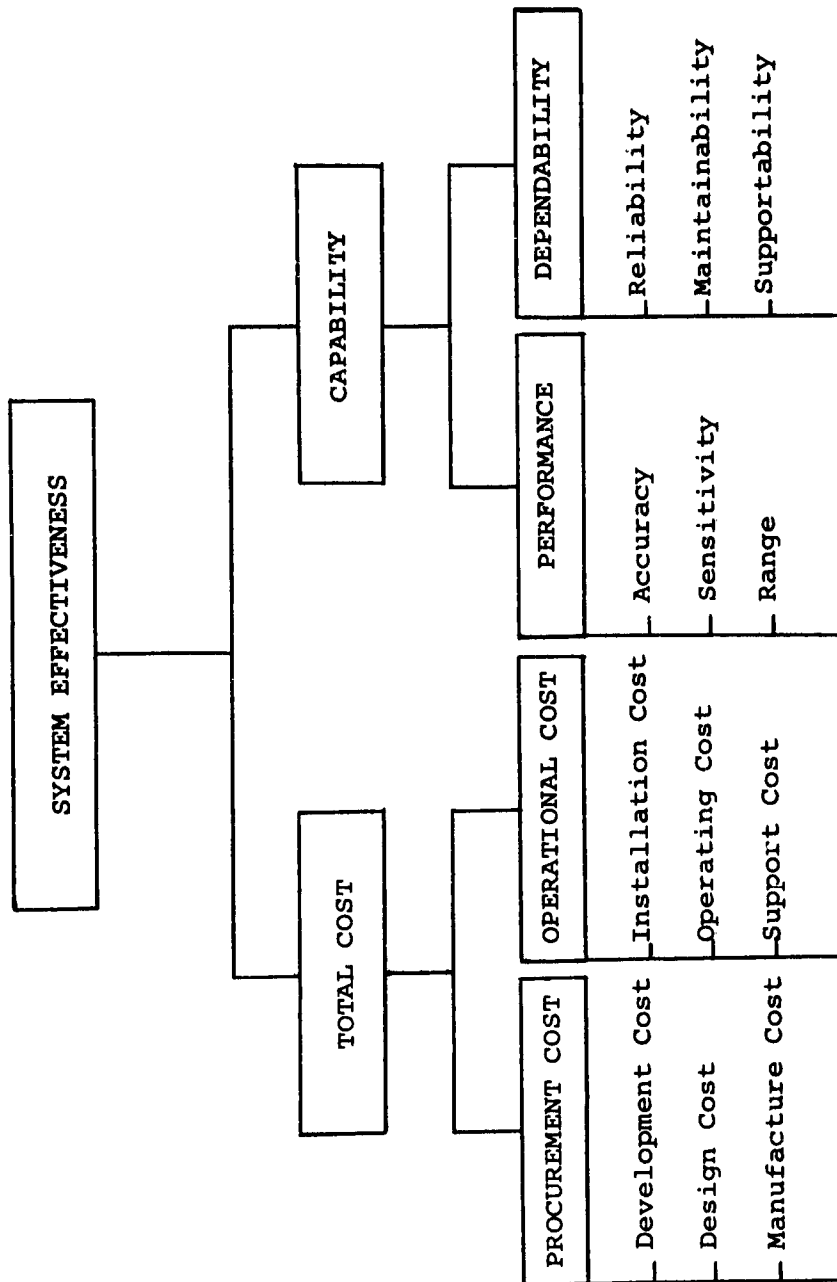
FIGURE 2.7. INGREDIENTS OF SYSTEM EFFECTIVENESS

2.3.3 The effectiveness of many of today's complex systems is seriously jeopardized by two extreme imbalances:

a. Increased complexity, new performance requirements and extreme environments have resulted in higher failure rates, greater requirements for maintenance, and lower availability of the present systems. Product capability has been compromised by strong emphasis on performance characteristics without the necessary balance of effort toward quantitative treatment and control of the qualities of dependability.

b. The costs of support for present military systems now involve from 10 to 100 times the original procurement cost. Much of this high cost is due to lack of recognition and control of reliability, maintainability, and support factors during the successive stages of development, production, and service use.

The principal system operational characteristics shown on the right half of Figure 2.7 must be balanced against the elements of cost shown on the left. Up to the present time very little organized effort has been applied to quantitative recognition and treatment of maintainability factors during the development and design phases. As a result, the costs of support, the requirements for maintenance time and the unavailability of equipments are exceedingly high. The system maintainability characteristic has not been balanced against the other ingredients of equipment effectiveness and performance.

2.4 Maintenance Indices

2.4.1 General – Because of the many facets of maintainability, the development of a single all encompassing figure of merit is not feasible at this time. Instead, a series of indices are needed to describe these multiple maintainability characteristics. This point is further verified by reviewing the various consequences relating to maintenance performance. In a broad sense, these include primarily (1) cost and (2) operational availability. These, in turn, may

be related to lower level measures such as man hours, down time, spares cost, etc. The indices and associated discussion presented here will be devoted to the providing of several numerics rather than a single number.

2.4.1.1 Another problem associated with measurement of maintenance stems from its dependence upon the factors of design, personnel, and support. Of these, design is the only one in the operational environment which remains essentially constant. Personnel and the support environment are susceptible to continuous change. With these variable conditions prevailing, it is not possible to cite specific values. Instead the most probable estimate made must be accompanied by statements concerning the expected variation which the numeric may take. These estimates must be further conditioned by details concerning personnel and support environment associated with the maintenance requirements.

2.4.1.2 Table 2.1, "Maintenance Indices," shows those factors which are considered most applicable in studying maintainability. They are listed under three general categories: time, cost, and capability related. The areas of index applicability with respect to specification, design, and customer have been illustrated.

2.4.2 Time Related Indices - Time is probably the most important measure of equipment maintainability. The two types of time indices that will be considered are equipment down time and technician time. In discussing the various indices two mathematical terms will apply to most of the ratios given. They are mean and M_{max} and are defined as follows:

a. Mean - The sum of a set of values divided by the number in the set.

b. M_{max} - A value which will encompass 95% of all times under consideration. For example, if a value of 80 minutes was given this would indicate that 95% of the maintenance tasks would fall between 0-80 minutes.

TABLE 2.1.

MAINTENANCE INDICES

INDEX	Area of Use		
	Specif-ication	Design	Cus-tomer
Time Related			
1. Total Down Time/Task			X
A. Active Down Time/Task	X	X	X
(1) Corrective Active Down Time/Task	X	X	X
(2) Preventive Active Down Time/Task	X	X	X
B. Delay Down Time/Task			X
(1) Corrective Delay Down Time/Task			X
(2) Preventive Delay Down Time/Task			X
2. Total Technician Time/Task			X
A. Active Technician Time/Task	X	X	X
(1) Corrective Active Technician Time/Task	X	X	X
(2) Preventive Active Technician Time/Task	X	X	X
B. Delay Technician Time/Task			X
(1) Corrective Delay Technician Time/Task			X
(2) Preventive Delay Technician Time/Task			X
3. Preventive Tasks/1000 Operation Hours	X	X	X
4. Corrective Tasks/1000 Operation Hours	X	X	X
Cost Related			
1. Support Equipment Cost/System/Year	X	X	X
2. Spares Cost/System/Year	X	X	X
3. Supply Cost/System/Year			X
4. Technician Cost/System/Year			X
Capability Related			
1. Availability	X	X	X
2. Repairability	X	X	
3. Manning Index	X	X	X
4. Operational Readiness	X	X	X

2.4.2.1 <u>Total Down Time/Task</u> - Total down time may be defined as the number of calendar hours that a system is not available for use, including time for active maintenance, both corrective and preventive, supply down time due to unavailability of a needed item, and waiting or administrative time, during which work is not being done on the system. To clarify the relation of down time to other operational considerations Figure 2.8, "Operation Profile," has been provided. Equipment investigation must assume some base or reference point. In the figure calendar time is the period of investigation, during which the equipment was scheduled to be in operation for a specified period and non-operational or off during the remaining period. Within the scheduled time it was possible to achieve a period of satisfactory operation, but the equipment was unable to operate consistently due to down time attributable to maintenance. Down time consists of active and delay times. Active maintenance down time is defined as that time during which work is being done on the system from the time of recognition of the occurrence of a failure to the time the equipment is back in operation at its specified performance and includes both preventive and corrective maintenance. Delay time relates to the calendar time spent on administrative activities, excessive supply time such as off base procurement, and other general areas which, although they preclude operation, cannot be considered productive towards task accomplishment. Down time is further described by the type of task, i.e. corrective or preventive. As indicated in Table 2.1 corrective and preventive active times are considered most appropriate for specification purposes since they are readily demonstrated by laboratory testing. Total down time, which also includes the delay factor, certainly would be of concern during operational use. Total down time/task therefore, is the total down time as defined above expended in the accomplishment of each maintenance task.

2.4.2.2 <u>Total Technician Time/Task</u> - This is the man minutes expended in the accomplishment of each maintenance task. This index may be further divided into active and delay technician time; which, in turn, is progressively expanded through the corrective and preventive categories.

2.4.2.3 <u>Preventive Tasks/1000 Operation Hours</u> - The number of preventive maintenance tasks in a 1000 hours period.

FIGURE 2.8. OPERATION PROFILE
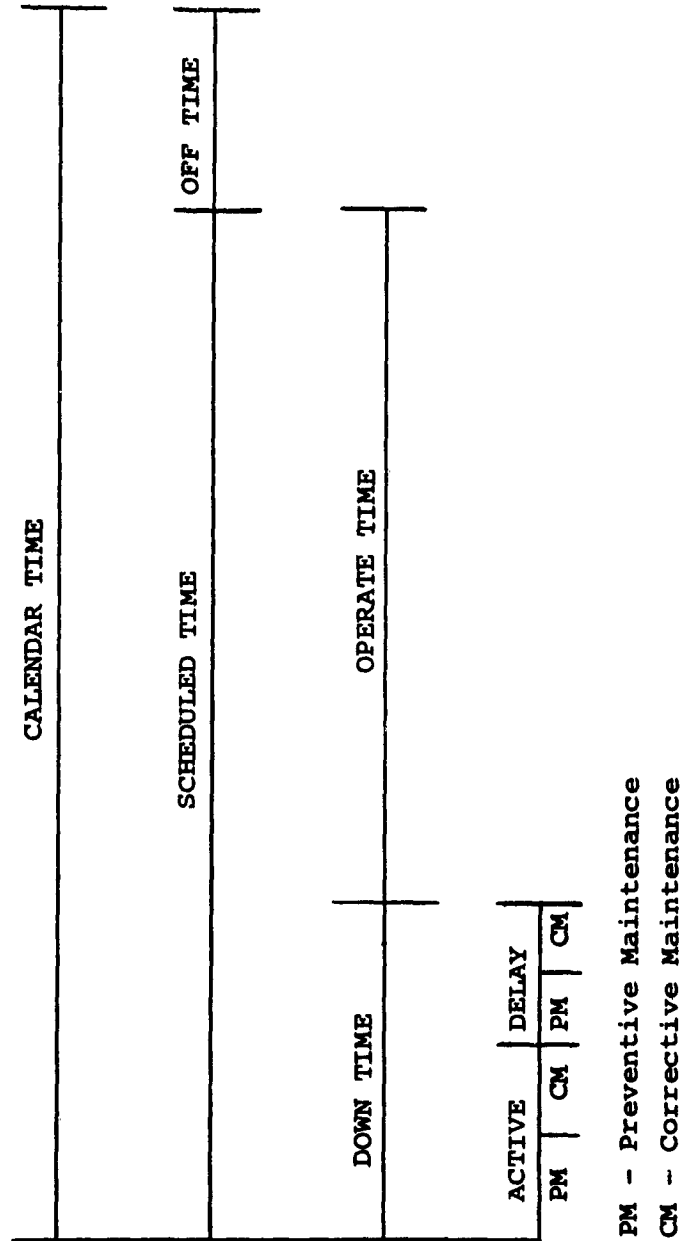
PM – Preventive Maintenance
CM – Corrective Maintenance

2.4.2.4 <u>Corrective Tasks/1000 Operation Hours</u> - The
number of corrective maintenance tasks in a 1000 hour
period.

2.4.3 <u>Cost Related Indices</u> - Maintenance costs per year
have been shown to exceed the original price of the prime
equipment.[27] Cost indices, when properly evaluated and
understood, provide a guide to reduction of costs in
the maintenance area.

2.4.3.1 <u>Support Equipment Costs and Spares Costs</u> - These
indices are important to the designer. These are two
cost areas which he may control directly through the
initial equipment design.

2.4.3.1.1 Support equipment which is necessary to service
the prime equipment includes test equipment, tools and
maintenance backup equipment. The correct complement of
support equipment must take into consideration trade-offs
between level of personnel used, complexity of test
equipment, and the associated costs in each area.

2.4.3.1.2 The cost of spares has become very important in
equipment provisioning and through maximum use of standard
parts this cost may be reduced. The use of standard parts
also permits a tighter control to be exerted in the procure-
ment of spares and, also, simplifies logistics and supply
problems. Evaluation of the two indices, support equipment
cost/system/year and spares cost/equipment/year will enable
design engineers to give each area proper consideration
whenever specifications indicate the recognition of the
indices is necessary.

2.4.3.2 <u>Supply and Technician Cost</u> - These two indices
are of interest to the customer. Technician cost/system/
year may be very high since this cost includes training,
facilities, administrative backup, etc. Training is a
most important area from a maintenance viewpoint. The
extent and degree of training required for maintenance
personnel is dependent to some degree upon equipment
design. This training is usually a customer's expenditure
or an added equipment cost. The designer must provide
equipment capable of being maintained by the typical
maintenance man unless a specification provides otherwise.

Spares requirements dictate supply requirements, Supply organizations may become large and expensive if not properly controlled. The index, supply cost/system/year is presented on a system base and will provide an indication of improvement of correction requirements when compared with other system supply costs.

2.4.4 <u>Capability Related Indices</u> - System or equipment capability is of the greatest interest when discussing system effectiveness. System capability includes operational requirements such as reliability, performability, repairability, maintainability, etc. Each area of interest is concerned with the maximum equipment performance under given circumstances.

2.4.4.1 <u>Availability</u> - The availability of a system or equipment is the probability that it is operating satisfactorily at any point in time when used under stated conditions. It is a widely used term in both industry and the military.

2.4.4.1.1 Availability may be stated in terms applicable to specifications (design) or operational use. These terms are inherent, operational, and use availability and are stated as follows:

a. Inherent availability (A_i) considers operate and active down time.

$$A_i = \frac{\text{Operate Time}}{\text{Operate Time + Active Down Time}} \qquad (2.1)$$

An alternate form:

$$A_i = \frac{\text{MTBF}}{\text{MTBF + MADT}} \qquad (2.2)$$

Where:

    MTBF = Mean Time Between Failures
    MADT = Mean Active Down Time

NOTE: This is the equation to use when considering only corrective maintenance. If there is active preventive down time the equation then becomes:

$$A_i = \frac{MTTM}{MTTM + MADT} \tag{2.3}$$

Where:

    MTTM = Mean Time To Maintenance (between occurances)

b. Operational availability (A_o) takes the same form as intrinsic availability (A_i) except total down time is substituted for active time. It is as follows:

$$A_o = \frac{Operate\ Time}{Operate\ Time + Total\ Down\ Time} \tag{2.4}$$

c. Use availability (A_u) considers off time in addition to total down time. It takes the following form:

$$A_u = \frac{Operate\ Time + Off\ Time}{Operate\ Time + Off\ Time + Total\ Down\ Time} \tag{2.5}$$

The calculated availability value from this expression could be very high on an equipment operating for short periods and having a long off time.

In the use of the above availability expressions, care should be taken when comparing values derived from one type of equipment with those obtained from another type of equipment. A clear statement should accompany each availability value describing how the value was calculated and why it was used.

2.4.4.2 Repairability - Repairability is the probability that when maintenance action due to equipment failure is taken, the system will be restored to a satisfactory operating condition in a given period of time. This expression is useful when considering system operational readiness. This probability (P_r) is stated by the following expression:

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$$P_r = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{u} e^{-u^2/2} du \qquad (2.6)$$

Where:

$$u = \frac{\log M_{ct} - \overline{\log M}_{ct}}{\sigma_{\log M_{ct}}} \qquad (2.7)$$

The probability of repair (P_r) can be evaluated by tables developing the cumulative normal distribution.[158] These tables are entered with values of $\underline{u}$ as calculated by equation 2.7.

2.4.4.3 <u>Manning Index</u> - This index is useful in determining maintenance manning requirements and is stated as follows:

$$MI = \overline{T}_{ct} \left(\frac{1000}{MTTM}\right) \qquad (2.8)$$

Where:

$\overline{T}_{ct}$ = Mean technician time

$\frac{1000}{MTTM}$ = Number of maintenance actions expected per 1000 hours

This index provides a point of compairson by which future equipment may be judged. It is important to recognize that a point by point comparison cannot be made without considering the complexity of the system.

2.4.4.4 <u>Operational Readiness</u> - Operational readiness may be defined as the probability that at any point in time a system or equipment is either operating satisfactorily or ready to be replaced in operation on demand when used under stated conditions, including stated allowable warning time. Mathematically, this may be stated as:

$$P_o = (P_a) (P_s) \qquad (2.9)$$

Where:

P_o = Operational Readiness

P_a = Probability that system is operationally available

P_s = Probability that system will operate satisfactorily for a time period (t).

The probability of availability (P_a) and probability of survival (P_s) may be related to repair and failure rate as follows:

$$P_r = \frac{\mu}{\mu + \lambda} \qquad (2.10)$$

Where:

μ = mean repair rate

λ = mean failure rate

and:

$$P_s = e^{-\lambda t} \qquad (2.11)$$

Where:

t = mission time

e = base of natural logarithms

The relations stated are based on the premise that underlying distributions are exponential, and that no administrative or other delay times are encountered in the repair process. Within a system, the same relations would hold, provided the above conditions are met and the individual equipments are non-redundant. System operational readiness may be expressed in terms of the operational readiness of each equipment by the following equation:

$$P_o = (P_{o1}) \ (P_{o2}) \ \cdots \ (P_{on}) = \prod_{i=1}^{n} P_{oi} \qquad (2.12)$$

By use of Equation 2.12 in association with Equations 2.10 and 2.11, the overall system operational readiness figure may be expressed in terms of individual equipment repair and failure rates. These expressions thus permit individual repair rates (maintainability goals) to be established for each equipment within the system through consideration of reliability and the overall system operational readiness requirement. This modeling technique is a simplification of a more rigorous process which may be invoked, dependent upon the complexity of the system and upon the number of factors to be considered.

2.5 Indices Computation

As previously stated the mean and maximum down time relations are the most important numerics required by current maintainability specifications. Their use is predicated upon the data being evaluated following the log-normal distribution. All calculations of indices should be proceeded by an examination to determine the applicability of the log-normal assumption (See Appendix II). There is some evidence that the exponential distribution may equally describe down time data.

2.5.1 Derivation of the Mean - Superficially it may appear that the geometric mean has a distinct advantage over the arithmetic mean for specification purposes. This point stems from the inherent log normal distribution of maintenance time and the relation of the geometric mean to the average of the log value and the median.

More directly:

$$\text{Geometric mean} = \sqrt[N]{X_1 \cdot X_2 \ldots X_N} \tag{2.13}$$

and:

$$\text{Mean of the logs} = \overline{\log X} = \sum_{i=1}^{N} \log X_i / N \tag{2.14}$$

but:

$$\sqrt[N]{X_1 \cdot X_2 \ldots X_N} = \text{antilog} \left[\sum_{i=1}^{N} \log X_i / N \right] \tag{2.15}$$

Thus:

$$\text{Geometric mean} = \text{antilog} \left[\sum_{i=1}^{N} \log X_i / N \right] \qquad (2.16)$$

For the log normal distribution the median is equal to the antilog of the mean of the logs or: [6]

$$\text{Median} = \text{antilog} \ \overline{\log X} = \text{antilog} \left[\sum_{i=1}^{N} \log X_i / N \right] \quad (2.17)$$

therefore, for the log normal distribution:

Median = Geometric Mean

These relations provide some merit for considering the geometric mean as the specifying maintainability parameter. Additionally, it is argued that due to the skew distribution, the geometric mean is more descriptive of actual maintenance time requirements.

2.5.1.1 However, the arithmetic mean is the better parameter for the following reasons:

a. It requires more data (increased sample size) to specify the geometric mean to the same accuracy as the arithmetic mean. The standard error for each is given by the following equation: [8]

$$\text{S.E (arithmetic)} = \frac{\sigma}{\sqrt{N}} \qquad (2.18)$$

$$\text{S.E (geometric)} = \frac{1.25\,\sigma}{\sqrt{N}} \qquad (2.19)$$

To secure equal standard errors, the sample size for the geometric mean must be 56% greater which is illustrated as follows:

$$\frac{\sigma}{\sqrt{N_1}} = \frac{1.25}{\sqrt{N_2}} \tag{2.20}$$

where:

N_2 = Sample size for geometric mean

N_1 = Sample size for arithmetic mean

then:

$$\frac{N_2}{N_1} = (1.25)^2 = 1.56, \text{ or } 56\% \text{ larger than } N_1$$

Since the sample size represents a direct cost in testing programs, the increased data requirements is a major disadvantage of using the geometric mean.

b. The arithmetic mean can be multiplied by task frequency to yield total maintenance time, a valuable relationship. The geometric mean can not be manipulated in this manner.

c. The point made concerning the geometric mean being more descriptive of the distribution than the arithmetric mean is not completely valid for maintenance time. Data indicates that the difference between the two values is on the order of 20 minutes which is not considered of major consequence.

2.5.1.2 Mean down time $(\bar{M}_t)$ includes both correction and preventive maintenance contributions. Numerically their relationship may be expressed as follows:

$$\bar{M}_t = \frac{F_c \bar{M}_{ct} + F_p \bar{M}_{pt}}{F_c + F_p} \tag{2.21}$$

Where:

$\bar{M}_t$ = mean down time

F_p, F_c = number of preventive and corrective maintenance tasks per thousand hours

$\bar{M}_{ct}$ = mean corrective down time

$\bar{M}_{pt}$ = mean preventive down time

The mean down time for preventive maintenance may be approximated by an emperical expression showing the relation of $\bar{M}_{ct}$ to $\bar{M}_{pt}$. This expression is:

$$\bar{M}_{pt} = \frac{\bar{M}_{ct}}{1.4} \qquad (2.22)$$

A more accurate estimate may be secured by applying the prediction criteria to a sample of preventive maintenance tasks, or obviously to direct measurement.

2.5.2 Derivation of M_{max} - Since maintenance times have been observed to be distributed log-normally, M_{max} (95th percentile) cannot be derived directly by using the observed maintenance times. However, by taking the logarithm of each of the values, the resultant distribution becomes normal, permitting utilization of the data in a normal manner. M_{max} is given by the following equation:

$$M_{max} = \text{antilog } (\overline{\log M}_{ct} + 1.645\ \sigma_{\log M_{ct}}) \qquad (2.23)$$

Where:

$$\overline{\log M}_{ct} = \frac{\sum\limits_{i=1}^{N_c} \log M_{cti}}{N_c} = \text{mean of log } M_{ct} \qquad (2.24)$$

and:

$$\sigma_{\log M_{ct}} = \sqrt{\frac{\sum\limits_{i=1}^{N_c} (\log M_{cti})^2 - (\sum\limits_{i=1}^{N_c} \log M_{cti})^2 / N_c}{N_c - 1}} \qquad (2.25)$$

= standard deviation of log M_{ct}

and:

N_c = number of tasks used in calculations

Two emperical expressions for derivation of the M_{max} have been developed as follows:

$$\log M_{max} \cong \overline{1.5 \log M_{ct}} \tag{2.26}$$

and:

$$\log M_{max} \cong \log \bar{M}_{ct} + 0.5 \tag{2.27}$$

These expressions are useful for purposes of estimation in the absence of specific data.

2.5.2.1 The equation:

$$\log M_{max} \cong \log \bar{M}_{ct} + 0.5$$

is derived as follows:

$$\log M_{max} = \overline{\log M_{ct}} + 1.645 \, \sigma \tag{2.28}$$

however:[6]

$$\log \bar{M}_{ct} = \overline{\log M_{ct}} + 1.1513\sigma^2 \tag{2.29}$$

solving for $\overline{\log M_{ct}}$:

$$\overline{\log M_{ct}} = \log \bar{M}_{ct} - 1.1513\sigma^2 \tag{2.30}$$

substituting this in the first expression:

$$\log M_{max} = \log \bar{M}_{ct} - 1.1513\sigma^2 + 1.645\sigma \tag{2.31}$$

From the maintenance data σ has been found to equal
.46510. Substituting this value in the above expression:

$$\log M_{max} = \log \bar{M}_{ct} - 1.1513 \ (.46510)^2 + 1.645 \ (.46510)$$

$$(2.32)$$

or:

$$\log M_{max} \cong \log \bar{M}_{ct} + 0.5 \tag{2.33}$$

2.5.2.2 Another expression for log M_{max} is given by:

$$\log M_{max} \cong 1.5 \ \overline{\log M_{ct}}$$

This may be derived empirically by forming the ratio (R):

$$R = \frac{\log M_{max}}{\log M_{ct}} \tag{2.34}$$

From the field data:

$$R = \frac{2.40559}{1.64051} \cong 1.5 \tag{2.35}$$

Sutstituting:

$$\log M_{max} \cong 1.5 \ \overline{\log M_{ct}} \tag{2.36}$$

2.5.3 Availability - Derivation of availability for a single channel equipment may be secured directly from the mean down time ($\bar{M}_t$) calculated by equation 2.21 and mean time between failures (MTBF). Inherent availability (A_i) is calculated by the use of the following expression:

$$A_i = \frac{MTBF}{MTBF + \bar{M}_{ct}} \tag{2.37}$$

(See NOTE following 2.4.4.1)

Operational or use-availability considers down time with
respect to administrative and logistic delays. Since such
delays are within the province of the user, it is not
feasible to evaluate this aspect during design. A ratio
of active to delay time has been calculated from the
field data, resulting in the following expression: (4)

$$\overline{\text{Delay Down Time}} = \frac{\overline{M}_{ct}}{1.89} \tag{2.38}$$

Operational availability may be approximated by calculating
the mean delay down time, by substituting $\overline{M}_{ct}$ in equation
2.38, then adding the value obtained to $\overline{M}_{ct}$ in equation 2.37.

2.5.4 <u>Technician Time</u> - The basic prediction method pro-
vides task time measurements in terms of down time. To
establish manning or cost data, it is necessary to consider
maintenance man-hours (Technician time). Again, the field
data has provided an expression by which technician time
(T_{ct}) may be related to active down time. (4)

$$\overline{T}_{ct} = 1.35 \, \overline{M}_{ct} \tag{2.39}$$

This equation may be used for approximation purposes, but
it has been observed that the ratio is not constant.
Figure 2.9, "Technician Time Vs. Down Time," provided a
more exact relationship. The technician data may then be
treated in a manner previously described to determine mean
technician time and other desired figures of merit.

2.6 <u>Maintainability Index Evaluation</u>

2.6.1 <u>Typical Values</u> - From the field data a number of
the indices presented in Table 2.1 were calculated. Table
2.2, "Derived Indices for Ground Electronic Equipment,"
shows the calculated values. Cost indices were not con-
sidered within the purview of this study and, therefore,
values for these indices were not developed. However, it
is recognized that cost studies within the framework of
the system effectiveness concept are essential but at the
present time are very difficult to determine. Costs
associated with many elements of the system effectiveness
structure are, as yet, not clearly defined and require a
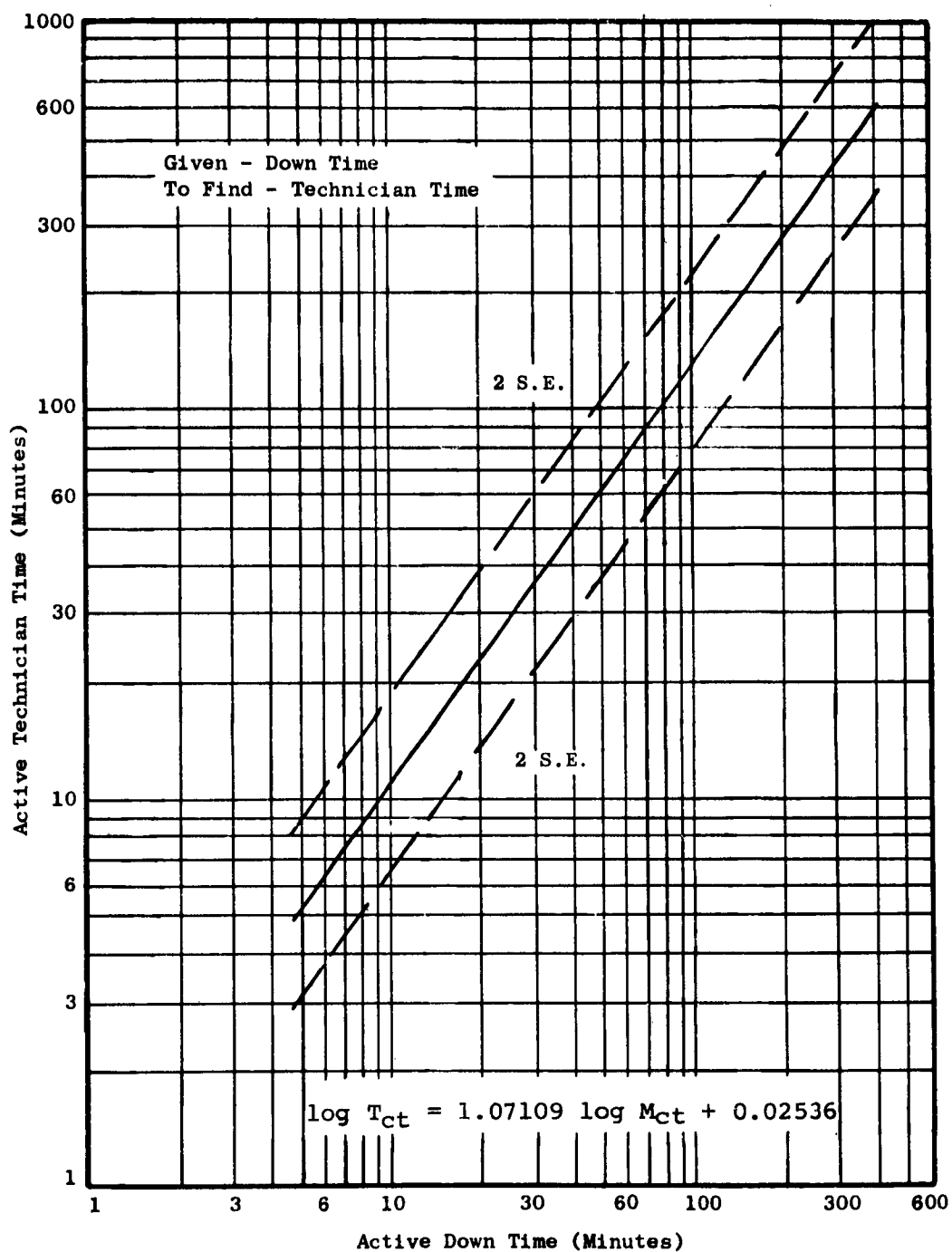
FIGURE 2.9. TECHNICIAN TIME VS. DOWN TIME

TABLE 2.2.

DERIVED INDICES FOR GROUND ELECTRONIC EQUIPMENT

Index	AN/GKA-5 Mean	AN/FST-2 Mean	AN/FPS-20 Mean	AN/FPS-6 Radar	AN/GRT-3/7 Commun.
1. Active Down Time/Task	96.7	57.22	51.4	42.97	53.10
2. Active Tech. Time/Task	124.0	74.0	70.0	82.59	65.63
3. Correc. Active Down Time/Task	97.6	56.0	67.0	94.04	63.31
4. Correc. Active Tech. Time/Task	128.1	76.1	94.6	148.87	77.72
5. Preven. Active Down Time/Task	92.7	59.4	17.9	18.01	12.28
6. Preven. Active Tech. Time/Task	105.7	70.1	17.9	27.96	17.28
7. Tasks/1000 Hrs. Oper. - Corr.	8.569	7.353	6.896	19.94	7.74
8. Tasks/1000 Hrs. Oper. - Prev.	1.327	1.281	2.597	5.95	13.4
9. Operational Availability	9.97973	0.98352	0.98920	0.95455	0.93086
10. Manning Index	20.49	10.62	11.11	77.1784	48.6520

NOTE: Indices 1 through 6 are expressed in minutes

thorough understanding of the economics of military organization and equipments.

2.6.1.1 Figure 2.10, "Probability of Repair," presents the combined repairability function for three typical ground systems. Here, the relationship between maximum down time (95th percentile) and the mean are illustrated. The 95th percentile observed was 254.4 minutes and the associated mean was found to be 72.6 minutes. These calculations were made on the basis of a log-normal distribution.

2.6.1.2 The data presented here will provide information concerning current maintainability levels and should prove useful for establishing design goals for future systems.

2.6.2 Confidence Limits and Tests of Significance - This section will present statistical methods for determining the relationship between specified and observed indices. Methods will be developed for testing both the mean and M_{max}.

2.6.2.1 Mean - The mean may be tested in two ways. These are summarized as follows:

a. Does the observed mean differ significantly from a stated value?

b. Does the mean not exceed a specified value?

The first test (a) is appropriate when comparing the means developed from two sets of data; for example, predicted versus field observed data. The t test forms an appropriate statistic for making this comparison and takes the following form:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_p \sqrt{1/N_1 + 1/N_2}} \qquad d_f = N_1 + N_2 - 2 \qquad (2.40)$$

Where:

$\bar{X}_1$, $\bar{X}_2$ = Means of the two data sets

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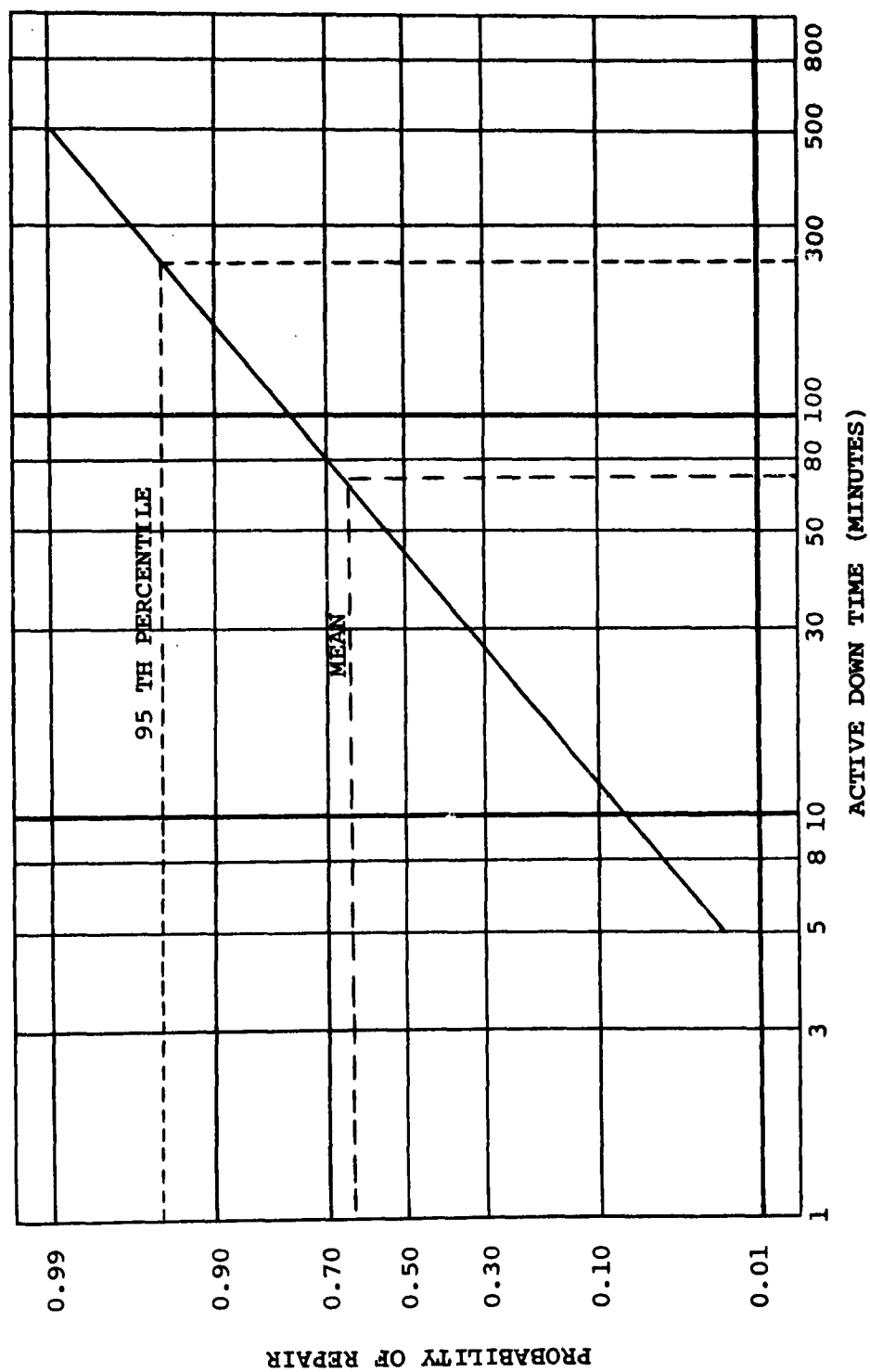
FIGURE 2.10. PROBABILITY OF REPAIR

N_1, N_2 = Respective sample sizes

S_p^2 = Pooled estimate of the variance

and:

$$S_p = \sqrt{\frac{(N_1 - 1)\, S_1^2 + (N_2 - 1)\, S_2^2}{N_1 + N_2 - 2}}$$ (2.41)

Where:

S_1^2, S_2^2 = respective variance for each set of data

and:

$$S^2 = \frac{\sum_{i=1}^{N} X_i^2 - \frac{\left(\sum_{i=1}^{N} X_i\right)^2}{N}}{N-1}$$ (2.42)

Where:

X_i = Task time in each set of data

To make the test, the hypothesis is made that there is no difference between the means of the two sets of data. Calculation of the $\underline{t}$ value using the above equations and referring to an appropriate table giving values of $\underline{t}$ versus degrees of freedom will permit a decision to be made regarding the hypothesis.

2.6.2.1.1 The second test situation (b) has its primary application to comparing a contractually specified mean to the value observed during maintenance testing. This test is concerned with determining if the computed mean can be considered statistically less than the specified value. The test situation is graphically illustrated in Figure 2.11 A, "Specification Testing." Here, the specified value has been depicted as the vertical line appearing to the right in the figure. The problem is to determine whether the mean or its possible range exceed the specification. Merely comparing the observed mean to
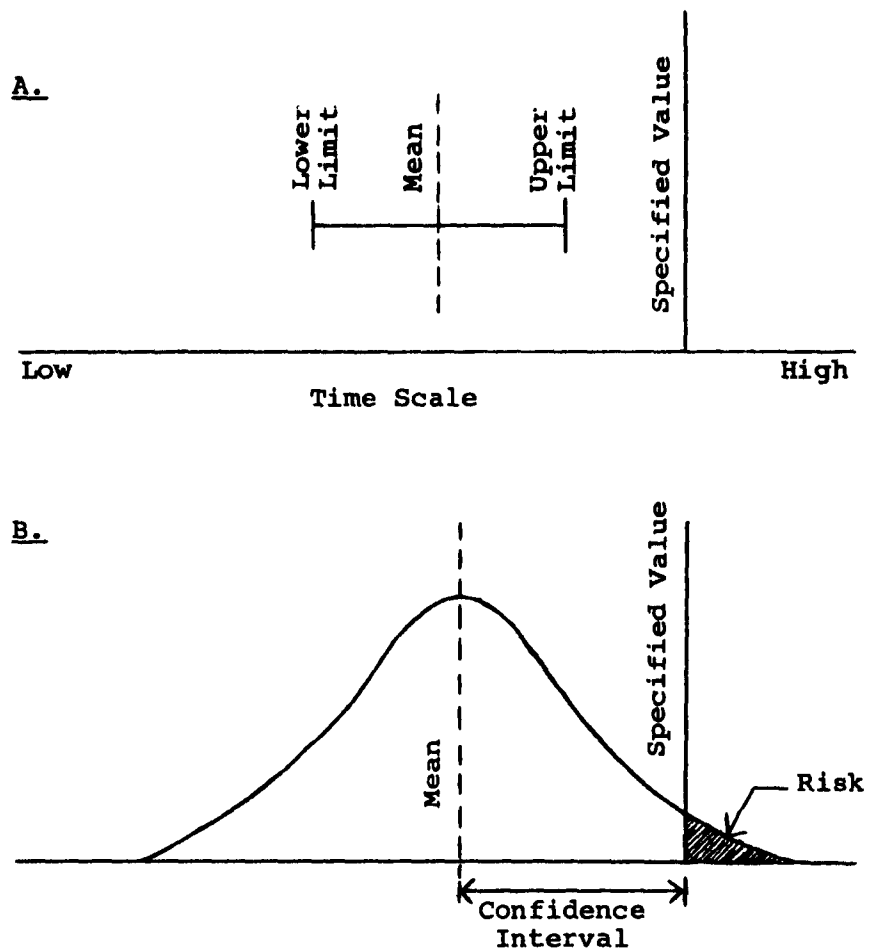
FIGURE 2.11.   SPECIFICATION TESTING

the desired value will not suffice, since the mean calculated from a sample is only an estimate of the true mean. However, it is possible to calculate the range in which true mean may lie on the basis of the sample data. This range is illustrated in the figure by the distance between the upper and lower confidence limits. These limits are dependent upon the confidence level desired, sample size, and the data itself. In this situation, the upper limit only is of concern, since the procuring agency must be assured that the true mean does not exceed the specified values. Since the upper limit marks the practical range of the true mean, it will be investigated further.

2.6.2.1.2 It has been found that the distribution formed by the sample mean is generally normal, hence, relationships appropriate to this distribution may be applied. The upper limit is thus given by the following equation:

$$UL = \bar{X} + Z\, \sigma_{\bar{X}} \tag{2.43}$$

Where:

UL = upper limit
$\bar{X}$ = mean
Z = confidence level
$\sigma_{\bar{X}}$ = standard deviation of the mean (standard error)

and:

$$\sigma_{\bar{X}} = \frac{\sigma}{\sqrt{N}} \tag{2.44}$$

Where:

σ = standard deviation of sample data (See equation 2.42)
N = sample size

The "Z" value is a constant determined by the contracting agency based on the level of confidence desired. The following table presents several typical values:

Z	Confidence	Risk
1.645	95%	5%
1.282	90%	10%
1.036	85%	15%
.842	80%	20%
.674	75%	25%

The confidence and risk columns may be interpreted by referring to Figure 2.11 B. In the figure the upper limit and the specified value have been drawn so that they coincide. In this situation the values for confidence and risk became exact. For example, using Z equals 1.282 with this condition prevailing, there is a ninety percent chance that the true mean is less than the specified value. Correspondingly, there is a 10 percent risk that the actual mean is greater than the desired level.

2.6.2.1.3 Choice of a testing level must always be a compromise. High confidence levels will require large sample size and more stringent maintainability achievement. Low confidence obviously increases the risk that the achieved maintainability will not meet imposed requirements.

2.6.2.2 M_{max} - Due to the unique nature of the mean the tests presented above are not directly applicable to the M_{max}. Test of the M_{max} will make use of its standard error which is given by the following equation:[12]

$$SE_{95} \cong 2.11 \frac{\sigma}{\sqrt{N}} \qquad (2.45)$$

Where:

SE_{95} = standard error for 95th percentile

σ = standard deviation of log M_{ct}

N = sample size

On the basis of prediction information, the calculated 95th percentile can be stated exactly. The range may

be determined in accordance with the following expression:

$$\log UL_{95} = \log M_{max} + Z (SE_{95}) \qquad (2.46)$$

Where:

$\log UL_{95}$ = log upper limit for 95th percentile

$\log M_{max}$ = log 95th percentile (see equation 2.26)

Z = confidence level

The upper limit value calculated using equation 2.46 when compared to the logarithm of the specified 95th percentile will provide a means of determining compliance. The Z values may be obtained by consulting the previous table which cross referenced them to different confidence and risk levels.

2.6.2.2.1 As in the case of the mean, compliance is proven if the upper limit is equal to or less than the specified 95th percentile.

2.6.2.2.2 Comparison of the 95th percentile derived from two sets of data (prediction-observed) is provided by the following statistic:

$$SE_{95d} \cong 2.11 \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}} \qquad (2.47)$$

Where:

SE_{95d} = standard error of the difference for 95 percentile

σ_1^2, σ_2^2 = respective variance of the log data

N_1, N_2 = respective sample sizes

2.6.2.2.3 The test is made by calculating the ratio of the difference between the 95th percentiles and the standard error of differences.

$$n_d = \frac{\log M_{max_1} - \log M_{max_2}}{SE_{95d}} \qquad (2.48)$$

If the value of n_d calculated is less than 2 the difference is not significant. Values of 2 to 3 are probably significant and over 3 definitely significant.

3. MAINTAINABILITY ENGINEERING PROGRAM

3.1 General

To assure that maintainability objectives are achieved, a maintainability program must be implemented to run concurrent with equipment design, development, production, and field operation. Such a program is established in conformance to requirements of military specifications requiring maximum equipment availability and reduced maintenance costs. The following paragraphs describe the organization, program tasks, and major milestones in a comprehensive maintainability program.

3.2 Organization for Maintainability

3.2.1 Organizational Needs - The maintainability management control function must provide for integration of efforts and operations to high organizational standards. The magnitude and specialized nature of most large maintainability programs prevent efficient accomplishment as an additional duty to the existing staff of engineers, supervisors, and managers. To be effective, it must be led by an assigned group in which is vested the responsibility for the maintainability effort, organization, and rules. Personnel trained in maintainability technology should be employed in each phase of the program from preliminary planning through final field evaluation. It is important that specific assignments be made to accomplish the necessary tasks during the development cycle and that these tasks are coordinated in each stage of equipment growth. Figure 3.1, "Program Control," illustrates a typical organizational approach to a comprehensive maintainability program.

3.2.1.1 Coordination - Individual tasks necessary to accomplish the program objectives can best be coordinated by project teams. These may operate on many levels within the project organization but should be headed by a maintainability coordinator for each group of related tasks. Personnel with training and experience commensurate with

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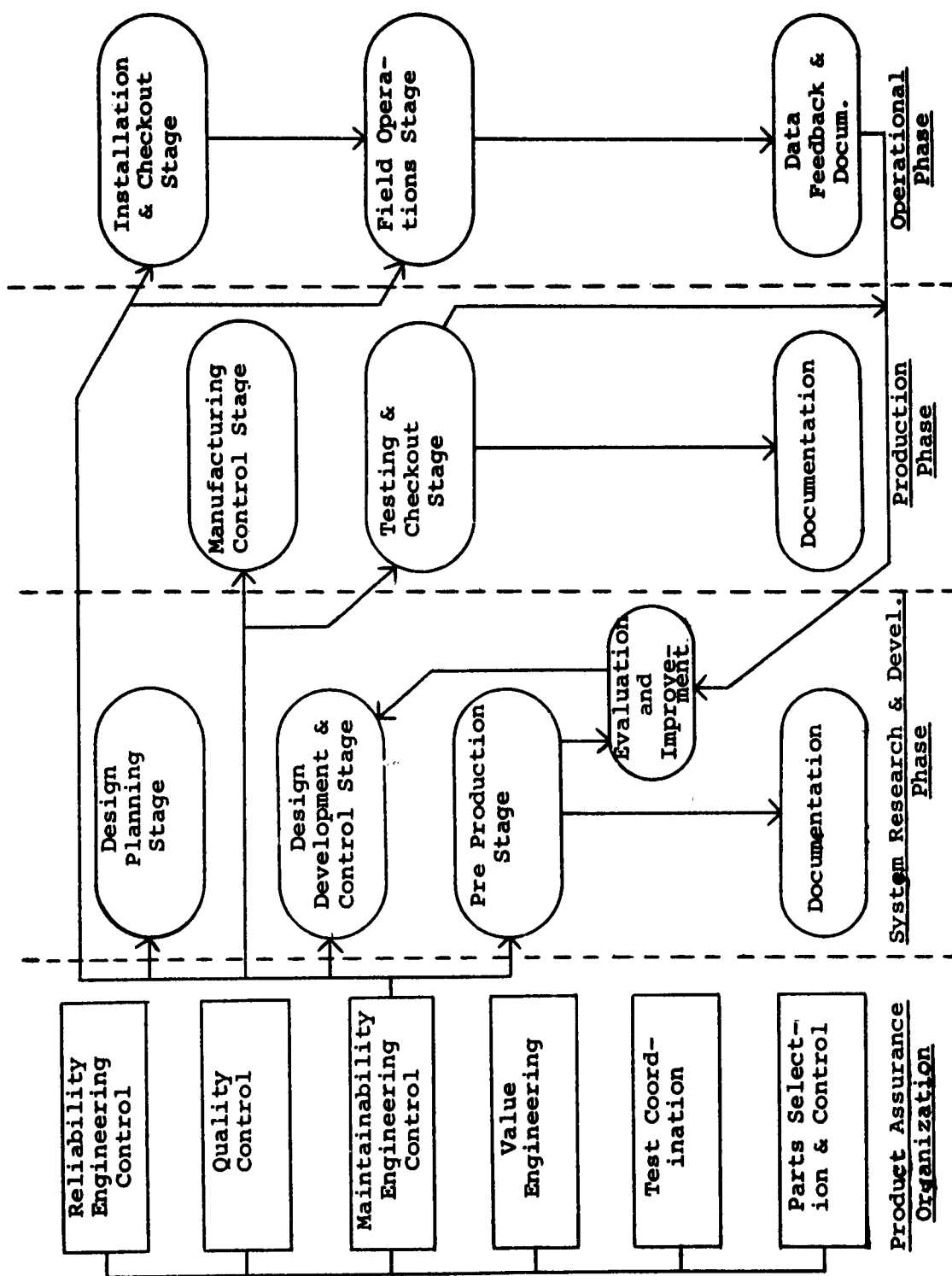
FIGURE 3.1. PROGRAM CONTROL

the scope of the tasks are a prerequisite for each team.

3.2.1.2 **Program Indoctrination** - The effective integration of efforts requires the orientation and indoctrination of all personnel responsible for conducting the maintainability program. Such a training program requires the full support of the product assurance management and the cooperation of all levels of personnel within the Maintainability Engineering and Control organization. Particular emphasis should be placed on the training program during which each member of the maintainability team must become thoroughly familiar with all important aspects of the system design, operation, and the maintenance philosophies to be utilized.

3.2.2 **Personnel Requirements** - To accomplish the necessary maintainability tasks, maintainability engineers, service specialists, circuit design analysts, statisticians, data analysts, human factors specialists, and mathematics consultants must be provided. The number of specialists in each category will vary with the size of the program. A limited maintainability program generally requires fewer associated personnel but this reduction in turn demands more diversified capabilities for the participating specialists. The following paragraphs describe the job descriptions of specialists generally needed to meet the program requirements.

3.2.2.1 **Maintainability Engineer** - The position ranges from coordinator of maintainability prediction and analyses tasks through leadership responsibilities within the Maintainability Engineering and Control Activity. In order to be responsive to these duties it is desirable that he has a background in electronic engineering and several years experience in the field of maintainability. Knowledge and experience related to electronic equipment design in a product line organization is important. Training in basic statistics with related maintainability experience is another important asset. He should be thoroughly familiar with all major military specifications, directives,

etc., pertaining to maintainability; together with an understanding of reliability, human factors, product assurance, and test planning.

3.2.2.2 **Maintainability Service Specialist** - The maintainability service specialist is subject to diversified assignments, as a specialist on certain tasks, as a lead engineer on specific tasks, or as a coordinator on several tasks. He will possibly be assigned tasks that involve recommendations for design improvements, development of maintenance and support procedures, actively participate in maintainability training, and direct subordinate level personnel in the accomplishment of maintainability design tasks. In order to solve diversified maintenance engineering problems, it is desirable that he has held electronic, electrical, or mechanical field engineering positions involving major technical complexities. This includes directing, participating, and advising customer personnel in the practical engineering aspects of installation and maintenance procedures. It is expected that previous experience has prepared him to analyze and evaluate electronic circuitry and mechanical problems encountered in the installation, repair, maintenance, and integration of equipments and systems.

3.2.2.3 **Circuit Design Analyst** - The circuit design analyst will be assigned to those tasks requiring engineering analysis, review, and evaluation for maintainability design. He will aid in the development of the test demonstration plan. To exercise his responsibilities effectively, the design analyst must have experience analyzing signal paths and circuit interface on equipments using the design concepts under contract. It is important that he has the ability to create engineering sketches of signal or data paths and connecting circuits of system diagrams. His capability of determining the trouble symptoms indicated by the failure of a component or part will be used extensively. The analyst should also be capable of recommending minor design changes to preclude undesirable maintainability features.

3.2.2.4 **Data Analyst** - The data analyst is responsible for processing statistical data and developing routines

for the collection and tabulation of these data. His
responsibilities will include performing the tasks re-
quiring maintainability analysis and prediction. Trans-
formation of these data into charts and graphs is in-
cluded in these responsibilities. The data analyst must
verify data and prepare summaries reflecting the status
of his efforts.

3.2.2.5 _Maintainability Monitor_ - The maintainability
monitor is responsible for witnessing and directing test
demonstration programs, monitoring installation and main-
tenance actions in the field, and assisting in the de-
velopment of appropriate maintenance reporting systems.
To perform these duties, he must have field experience
in actual equipment maintenance. It is desirable that
this experience be heavily weighted on equipments with
design concepts closely related to the contracted equip-
ments.

3.2.2.6 _Consultants_ - Consultants may be used as follows:

(a) Statistician: The statistician is to be uti-
    lized usually on a part time basis as a consult-
    ant capable of using higher level statistical
    techniques. He will participate in those tasks
    requiring analyses, prediction, and building of
    the maintainability mathematical model.

(b) Mathematician: The mathematician will be re-
    sponsible for developing the maintainability
    mathematical model. In this capacity a complete
    familiarity with product line equipment develop-
    ment is essential.

(c) Human Factors Specialist: The human factors
    specialist is generally utilized on a part time
    consulting basis for developing the human factors
    requirements of the program. (see paragraph 3.
    3.2.2). It is conceivable that this specialist
    is utilized on a full time basis on very large
    development projects.

3.2.3 _Functions of the Organization_ - It is impractical

here to put forth an optimum maintainability organization since it will be dependent upon the organizational structure of the contractor and the project size. It is however, deemed appropriate to include in this report a very general organizational flow which emphasizes the position of importance that maintainability control plays in the performance of a program. Figure 3.1 presents an approach to the logical administration and management of a formal maintainability program. This diagram describes the product assurance organization, one function of which is the Maintainability Engineering and Control activity. This activity is responsible for exercising control of the maintainability program from the beginning of the research and development phase through the operational phase. The significant stages within each phase of the program are major stepping stones to the final accomplishment of the overall program. Each stage must be satisfied through the consummation of a group of task requirements. These tasks are described in detail in subsequent paragraphs.

3.3   Task Requirements

3.3.1   General - To carry out the requirements of the program as outlined in previous paragraphs, a number of tasks must be performed to accomplish the objectives. These tasks are briefly described below. Each is a major requirement in providing a comprehensive maintainability program; however, it will be assumed that the tasks will be regulated in scope to be consistent with the magnitude of the particular development program.

3.3.2   System Research and Development Phase - The stages and tasks to be performed within the system research and development phase are described in the following paragraphs. (See Figure 3.2, "System Research and Development Phase.")

3.3.2.1   Design planning stage - This stage is the period of design development and may include some preliminary design work for the initial proposal. During this period, a comprehensive program plan must be developed, a mathematical model formulated, and a maintainability design policy manual published. The required specifications are reviewed
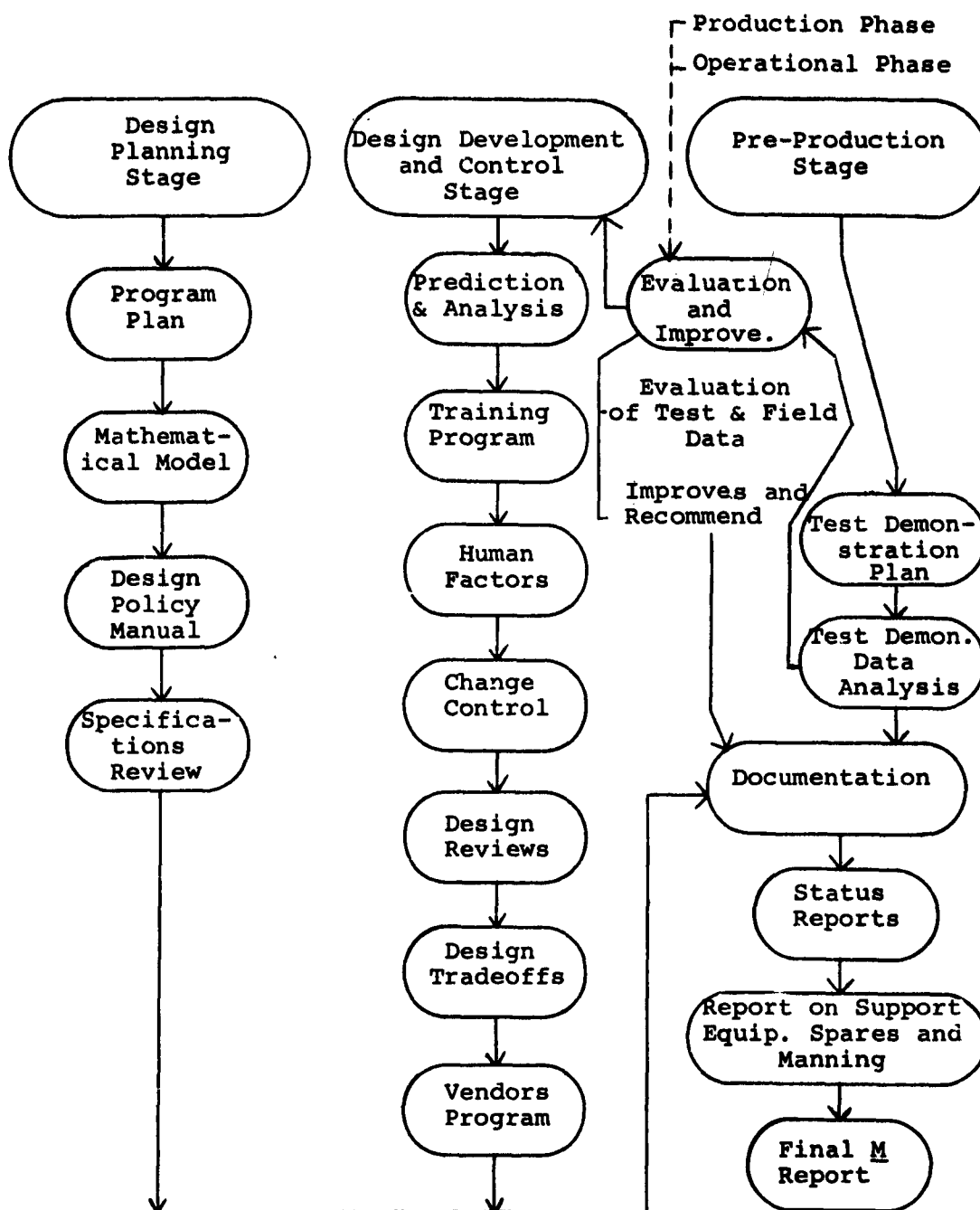
FIGURE 3.2.   SYSTEM RESEARCH & DEVELOPMENT PHASE

for applicability. The achievements, problems and corrective actions taken during this planning stage are to be documented in the maintainability status reports.

a. <u>Program Plan</u> - A maintainability plan must be developed which defines the maintainability requirements and means of accomplishment. The plan should contain objectives, plans, goals, and milestones which can be demonstrated on a time basis. The plan will describe in detail each required maintainability task to be implemented. Initial preparation of the program plan begins immediately after contract award and may be modified as necessary as the program progresses. This plan provides a guide for all design, production, and product assurance engineers.

b. <u>Mathematical Model</u> - A system mathematical model must be developed to serve as goals for maintainability, availability, etc. It serves as a standard for demonstrating the design achieved. The mathematical model will be used in determining the maintainability status and effectiveness of the system during all stages of design, development, and testing. It will provide a basis upon which decisions may be made regarding the relative importance of various design features. To express adequately the maintainability program in mathematical terms, identification of maintainability factors are to be established and a proper set of indices determined in compliance with the program requirements. Other parameters such as equipment reliability and cost factors are essential inputs to the model equations.

c. <u>Design Policy Manual</u> - A maintainability design policy manual should be developed and distributed by the maintainability engineering and control activity. This manual is to be available to the design engineers and subcontractors and used as a guide for maintainability design criteria. Design techniques are to be described for performing rapid recognition of the equipment malfunctions, ease of

component replacement, accessibility, etc. It
should also specify design which permits use of
minimum personnel, minimum tools and test equip-
ments, and maximum safety for personnel and equip-
ment.

d. Specifications Review - Upon award of the develop-
ment contract, a complete and thorough study of
maintainability and other related product assurance
specifications must be accomplished. As new equip-
ment design specifications are developed, pertinent
maintainability design criteria must also become
part of the specification. The contractor's program
should provide for periodic review and evaluation
of these requirements and updating as required.

3.3.2.2 Design Development and Control Stage - Maintain-
ability design control will be initiated and expedited
through various maintainability tasks which must be ac-
complished. These include the analyses and predictions,
training of project design personnel, human factors engi-
neering, change control, design reviews, trade-offs, and
vendors programs. Task accomplishments are to be docu-
mented in the status reports and updated as required.

a. Prediction and Analysis - An analysis must be
undertaken to make preliminary maintainability
predictions. Since this will be done before
design has been completed, a gross estimate must
be made. The first detailed analysis will be
performed later in the development. Additional
maintainability analyses will be performed in the
preprototype and/or prototype stages. The data
for these analyses shall be supplied through the
test demonstration program. These are to be
utilized in equipment or system evaluation and
improvement actions and as quantitative backup
information for design review.

b. Training - All engineering personnel participating
in the equipment or system development program must
be maintainability oriented. A training program is

to be established to attain that end. Information is presented to program personnel through lectures and on-the-job training conducted by the maintainability control activity. The following subjects should be covered in meeting this requirement:

(1) Objectives
(2) Organization
(3) Specifications
(4) Analysis and Prediction
(5) Design Policy Manual
(6) Test Demonstration
(7) Failure and Maintenance Reporting and Analysis

On-the-job training will be continually provided for the purpose of keeping personnel updated on current analytical results, changes in program procedures, and supplying information pertinent to the latest maintainability design concepts.

c. Human Factors - Equipment design concepts are to be reviewed for logic, display control configuration, and operations with emphasis on system maintainability. Specific human factors criteria are to be developed for the equipment or system in compliance with contract requirements. A list of human factors design guidelines should be generated suitable for use in design direction. These guidelines will establish design techniques which satisfy human aspects within maintainability limitations. The human factors specialist will participate in design reviews to ensure that a high standard of human engineering is maintained.

d. Change Control - Once final drawings have been released, no drawing changes affecting maintainability may be made without the approval of a member of the maintainability engineering and control activity. The responsibility of this maintainability specialist assures that changes affecting maintainability design are handled expeditiously and that any changes affecting the maintainability of the equipment are carefully reviewed.

e. Design Reviews - Design reviews must be conducted
    to insure that maximum maintainability has been
    achieved throughout the development cycle. A
    design review board should convene at least one
    time in each stage of development to discuss the
    logical flow, electrical circuitry, and mechanical
    aspects of equipment design applicable to maintain-
    ability. Additional review meetings should be sched-
    uled as necessary, and prior to such meetings, board
    members are to be supplied with pertinent information
    on the equipments scheduled for consideration. This
    information will include circuit schematics, assembly
    drawings, parts lists, assembly mock-ups if avail-
    able, and test data applicable to the equipment
    being reviewed. It is the responsibility of the
    board to provide the project design engineer with
    recommendations wherever a maintainability improvement
    is possible. The design engineer is to respond, either
    stating his intention of incorporating the recommenda-
    tions or showing justification for non-compliance.
    These recommendations are to be documented in a
    design review report issued by the review board
    chariman.

f. Design Tradeoffs - In early equipment development,
    it is necessary to consider designs which, while
    conforming to maintainability specifications, do
    not always meet other specified requirements. These
    include requirements such as: operational require-
    ments, reliability of equipment, economic limita-
    tions, and performance requirements. Equipment
    design characteristics, however, should be evalu-
    ated for maintainability prior to design trade-off.
    The mathematical model developed in the early design
    stage may be utilized as an instrument for control-
    ling trade-offs.

g. Vendors Program - A program must be incorporated to
    provide vendors and subcontractors with maintainabi-
    lity guidelines and specifications. Copies of the

design policy manual and other pertinent documentation are supplied to them. It is essential that contractor work statements to vendors or subcontractors clearly specify maintainability requirements. Compliance to these will be qualified through periodic visits to the vendor or subcontractor's plant and/or through certification of compliance.

h. Evaluation and Improvement

    (1) Evaluation of Test and Field Data - Evaluation of maintenance data feedback from the test areas and from the field provides valuable information for two purposes; first, for supporting design improvement recommendations and second, for the verification of maintainability predictions. An engineering evaluation of this data will also disclose gross maintainability problems. The evaluation task begins during the preproduction (prototype) stage and will continue throughout a portion of the field operations phase.

    (2) Improvement Recommendations - Recommendations for improving the design of the subject equipments must be developed, justified and submitted for proper action. The improvement recommendations are generally a result of the analysis and evaluation task that has been performed. These recommendations will be applicable to the equipment design affecting maintainability parameters. It should be noted that recommendations for design change must be reviewed by the design review board.

3.3.2.3 Preproduction stage - The preproduction stage is the period where the prototype or the last experimental model is developed prior to production. Presumably, design of the equipment has been stabilized and efforts are concentrated in demonstrating its maintainability and valida-

ting early predictions. These goals are achieved through test demonstrations. Data from the demonstration tests are analyzed and the resulting information evaluated. Recommendations for improvement are made to eliminate maintainability design problems and inconsistencies. The following are some tasks which should be accomplished:

a. <u>Test Demonstration Plan</u> - A plan is to be prepared providing a statistical method and detailed procedures for demonstrating equipment or system maintainability. This program will provide reasonable assurance that the maintainability design requirements have been met, that the predicted maintenance times are valid, and will point out gross problem areas affecting the maintainability of the system. Where invoked, MIL-M-26512 (USAF) Appendix A, "Maintainability Test and Demonstration, Requirements for Systems and Equipments," shall be followed. Where not required, this specification will serve as a guideline for establishing a demonstration plan in the absence of a specific equipment maintainability test plan. The procedure specified in MIL-M-26512 requires that:

   (1) The contractor perform time studies of maintenance task simulation of system characteristics in actual operation. Time to accomplish each maintenance task shall include recognition, diagnostic, repair, and checkout times.

   (2) The prototype, or the first production model where no prototype is available, shall serve as the demonstration vehicle.

   (3) For the purpose of maintainability demonstration, excessive supply down time and all administrative down time shall be excluded.

   (4) Corrective and preventive maintenance tasks shall be selected for the demonstration tests.

(5) Resulting data shall be used to determine mean corrective maintenance down time ($\bar{M}_{ct}$), mean preventive maintenance down time ($\bar{M}_{pt}$), total mean down time, and maximum down time (M_{max}).

b. **Demonstration Data Analysis** - The data compiled as a result of the test demonstration program must be analyzed in accordance with the requirements specified in MIL-M-26512, when invoked. This data shall be used to determine the mean corrective maintenance down time, mean preventive maintenance down time, total mean down time, and maximum down time. The data will also be utilized for deriving other indices specified in the demonstration plan.

3.3.3 **Production Phase** - The stages and tasks within the Production Phase are described in the following paragraphs. (See Figure 3.3, "Production Phase"). The maintainability requirements and objectives to be accomplished in this phase must be consistent with those established in the design development phase.

3.3.3.1 **Manufacturing Stage** - During the manufacturing stage of the contracted equipments, close surveillance must be provided to assure that quality assurance requirements and maintainability specifications are maintained. Changes and modifications to the original design must reflect highest maintainability practices. Status reports will show certification that this has been accomplished according to specifications.

a. **Quality Control** - The quality control activity will maintain a high deg ae of workmanship and manufacturing standards with respect to maintainability. Poor quality practices must be isolated and corrective action initiated to preclude maintainability problems in the field. Quality problems producing poor maintainability practices would include, e.g., situations where a cover plate was secured to the chassis with burred screws making removal of the plate difficult, or where a poor solder connection to a test panel indicator light might increase the diagnostic time of the maintenance action.
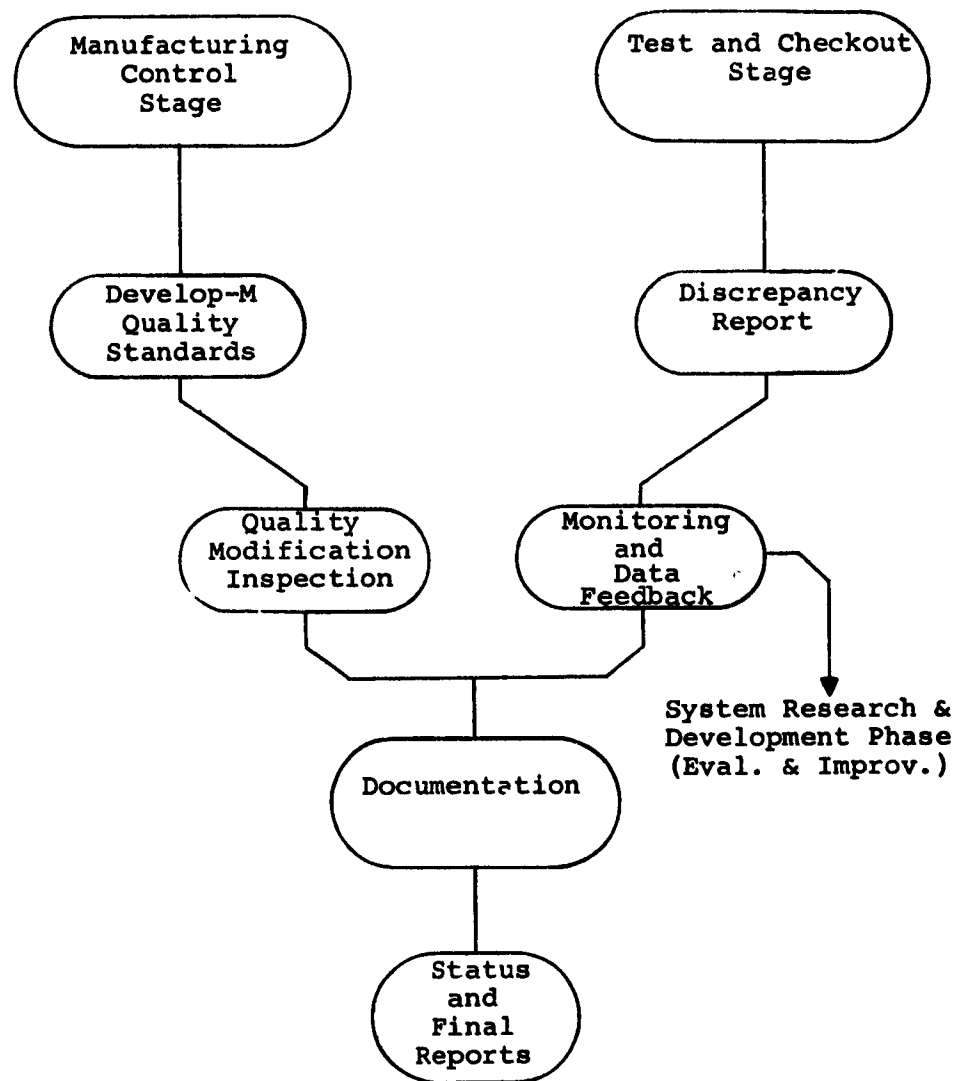
FIGURE 3.3.   PRODUCTION PHASE

At least one member of the maintainability control activity must be actively engaged in monitoring manufacturing quality control activities. The specific task function will include reviewing or developing manufacturing and workmanship standards for maintainability quality control. In addition, quality inspectors will be trained on the maintainability factors requiring close scrutiny. A periodic inspection of the equipment will also be within the scope of this responsibility.

b. <u>Modification and Change Control</u> - Close surveillance of changes or modifications to equipment design, hardware replacements, or test procedures will be practiced. Approval of these must be granted before changes or modifications can be initiated. This task will require coordinated effort between the design and the manufacturing activities. Additional design reviews as well as updated maintainability analyses are essential.

3.3.3.2 <u>Checkout Stage</u> - After completion of the manufacturing cycle normal qualification and acceptance tests are required. Valuable maintenance data becomes available and is reported to the evaluation and improvement activity through the media of discrepancy reports.

a. <u>Discrepancy Reporting</u> - Equipment maintenance that occurs in the testing areas is reported to the evaluation and improvement activity. Since these maintenance procedures and troubleshooting approaches are not always consistent with those found in field maintenance, the value of these data for validating earlier predictions is in question. However, if the report is designed correctly, it becomes an effective device for collecting data useful in detecting design deficiencies. The development of the discrepancy report form should be coordinated with the other product assurance activities.

b. **Monitoring and Data Feedback** - Maintainability moni-
tors should witness qualification and acceptance tests.
The presence of monitors during testing, gives as-
surance that all pertinent maintenance actions will
be reported. It is important that discrepancy re-
ports be channeled to the maintainability control
group. There the analysis, evaluation and recom-
mendations for improvement of the design for main-
tainability will be initiated.

3.3.4 **Operational Phase** - The stages and tasks within the
operational phase are described in the following paragraphs.
(See Figure 3.4, "Operational Phase.") The final validation
of maintainability predictions is accomplished during the
operational period.

3.3.4.1 **Installation and Checkout Stage** - Data are accumu-
lated relative to transportation, storage, assembly, em-
placement, and checkout and sent back to the evaluation
and improvement activity. These data are analyzed and re-
commendations for product improvement initiated for fu-
ture equipments. If a problem needs immediate attention,
proper engineering change notices may then be issued and
modifications sent to the field. Storage, transportation,
emplacement, assembly, and checkout of contracted equipments
are general installation practices preceding the normal
operating cycle of the equipment. As these are accomplished,
information becomes available demonstrating maintainability
design adequacy. Much of this information becomes an impetus
to product improvement for redesign or retrofit. To accom-
plish this: forms must be developed, instructions issued,
and methods provided to assure that an accurate reporting
system is implemented. The most effective method to assure
accurate reporting is through monitoring of field locations
at installation of initial equipments or systems. Main-
tenance actions prior to normal operation are to be
recorded in the maintenance log and included in a periodic
report. Failure report forms are not necessary prior to
normal equipment operation.
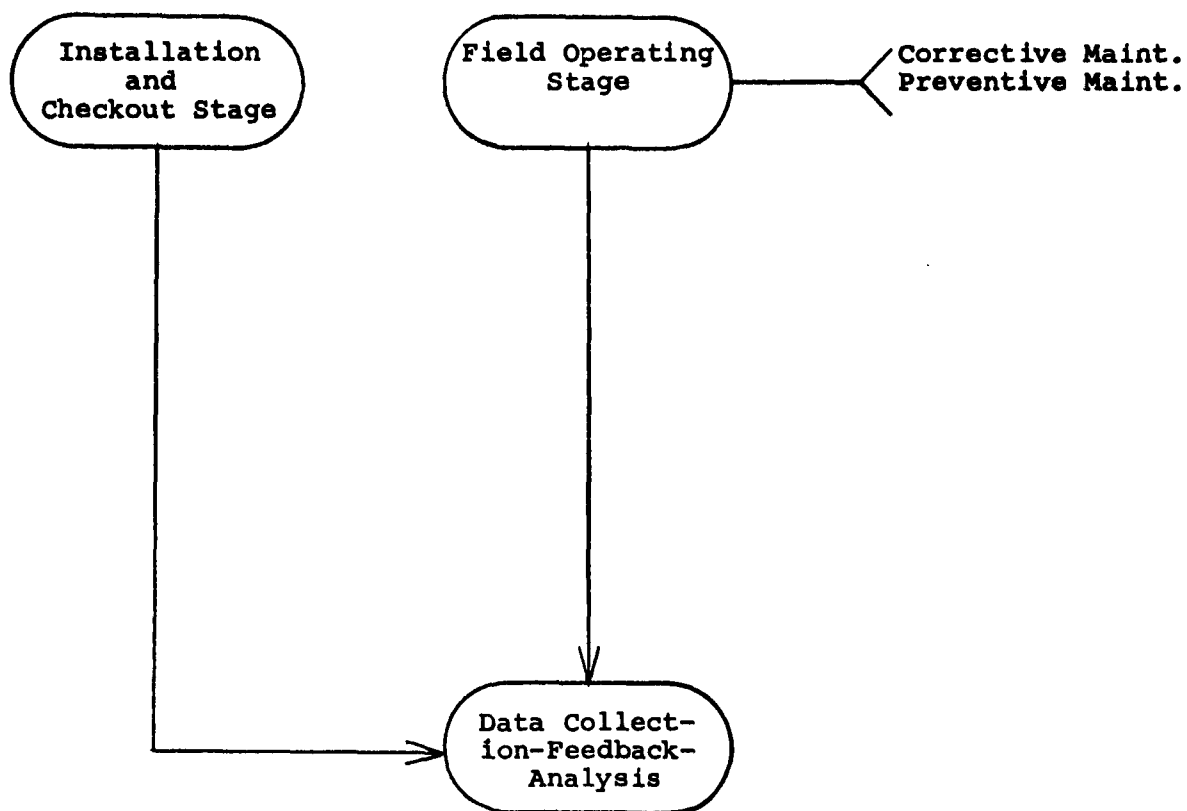
System Research & Development Phase
(Evaluation & Improvement)

FIGURE 3.4.   OPERATIONAL PHASE

3.3.4.2 <u>Field Operating Stage</u> - A permanent failure
reporting system must be developed and instituted at all
equipment sites. The maintainability part of the reporting
system is to be developed by the field maintenance
organization under supervision of the product assurance
activity. The maintainability control activity will
incorporate factors into the report form for recording
useful maintainability data. The active maintenance
data reported are to be analyzed and used to validate the
predicted maintainability figures. The gross problem areas
will also be isolated. The classification of data shall
fall into the corrective and preventive maintenance
categories. These are discussed in further detail in the
following paragraphs.

    a. <u>Corrective Maintenance</u> - The maintenance per-
formed on a non-scheduled basis to restore
equipment to satisfactory condition is class-
ified as corrective maintenance. This type
maintenance action is to be reported through
the established failure reporting system.
The failure report shall differentiate be-
tween corrective and preventive type actions
and will provide for entries relative to
recognition, diagnostic, repair, checkout,
administrative, and waiting times. In
addition, the failure report will include
the number of maintenance personne per-
forming the action, a narrative relating
unique skill problems encountered, special
test equipment needed, and other items re-
flecting unusual maintenance practices.

    b. <u>Preventive Maintenance</u> - The maintenance per-
formed to sustain a system or equipment in
satisfactory operation by providing systematic
inspection, detection, and correction of
incipient malfunctions before they occur or
develop into major malfunctions, is classified
as a preventive maintenance type action. These

actions are reported through the established failure reporting system. Actions which can be accomplished while equipment is in normal operation without interruption need not be reported. The failure report will be completed for the entire maintenance action for all valid preventive maintenance actions.

3.4 Documentation

3.4.1 **Status Reports** - Status reports should be provided for all project engineering groups, contract administrators, program management, and the customer. This report will be revised periodically to reflect the progress of the maintainability program, its achievements, and the problem areas which have occurred. In addition, the report will reflect deviations from the assigned objectives and corrective actions. It will cover, in detail, the analysis and predictions performed during the required stages.

3.4.2 **Support Equipment, Spares, and Manning Report** - A report is to be published establishing the requirement for support equipment, spares supply, and manning necessary to maintain the designed equipment at full effectiveness. This report is to define the minimum requirements to maintain the equipment or system at the predicted functional availability. The basic tools for making such estimations shall be the reliability and maintainability predictions, and other pertinent data reflecting logistic requirements. The factors most pertinent to personnel requirements includes skill levels, manning, and resources under the specified service environment. When failure rate information, the predicted maintenance times, and input data discussed above are available, a complete maintenance study will be performed resulting in test equipment and spares allocation and manpower requirements determinations.

3.4.3 **Final Maintainability Reports** - A final maintainability report for each phase will be prepared summarizing the results of maintainability program within that period.

These reports will include certification that maintainability specifications have been met. Some of the items to be covered in the Systems Research and Development Phase final document are:

a. Program Organization

b. Description of Program Plan

    (1). Summarization of Program Plan
    (2). Changes throughout program

c. Summary of Mathematical Model

d. Maintainability Analyses

    (1). Final Predictions

        (a). Individual equipments
        (b). Major subsystems or assemblies
        (c). Overall system

    (2). Summarization of Analytical Approach

    (3). Appropriate graphic presentations of specified maintainability indices

e. Description of Maintainability Training Program

f. Discussion of each of the accomplished tasks not detailed above

    (1). Design changes
    (2). Design reviews
    (3). Demonstration plan
    (4). Improvement recommendations
    (5). Human engineering

g. Summary of the recommended support equipment, spares, and personnel requirements. NOTE: These are detailed on a separate report

h. Certification of compliance with maintainability specifications

i. Recommendations for future designs

3.5 Milestones - Scheduling

3.5.1 General - In order to implement the maintainability program some method will be needed which will coordinate all tasks into a master plan. This plan was designed to meet the following objectives:

a. Have the flexibility permitting revision and up-dating at any point in the program.

b. Show the various tasks and milestones, and approximate times required to accomplish each.

c. Show each event, the coordinated sequence of occurrence, and the interrelationship of each.

d. Provide valuable impetus for determining project costs and the most economical allocation of personnel.

The ensuing paragraphs and related charts (See Figure 3.5 "Maintainability Program Schedule Plan (Research and Development Phase" and 3.6 "Maintainability Program Schedule Plan (Production and Operational Phases") provide a plan for implementing the maintainability engineering program discussed in this section. This program schedule encompasses the three phases of effort and uses an eighteen month time period to complete the entire program. This time base is used as a hypothesis for the purpose of developing the relationships of program events and milestones rather than to program a specific equipment application.

Since phases, stages and tasks frequently overlap, the event time estimates presented may be questioned. In each
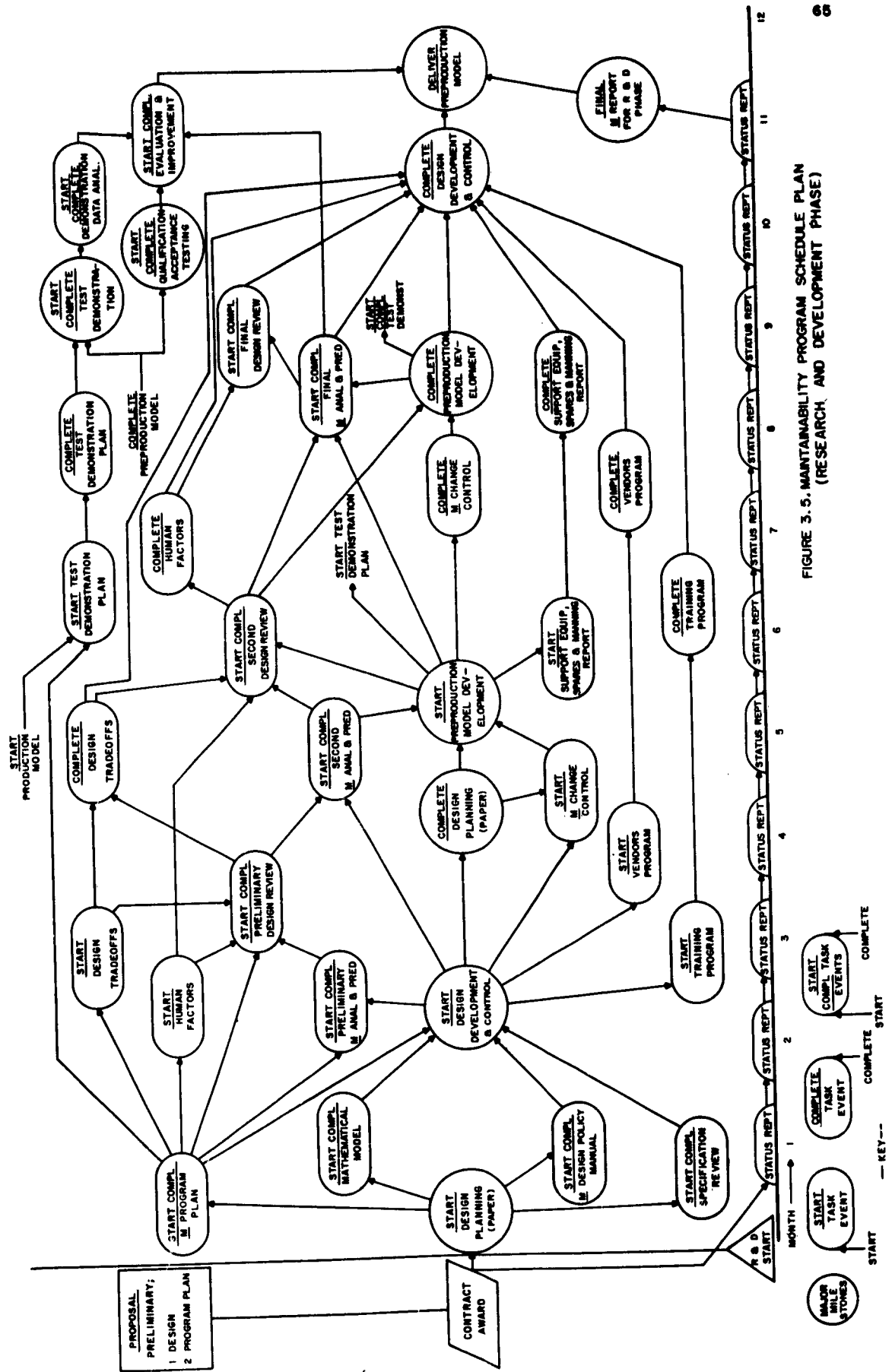
FIGURE 3.5. MAINTAINABILITY PROGRAM SCHEDULE PLAN
(RESEARCH AND DEVELOPMENT PHASE)
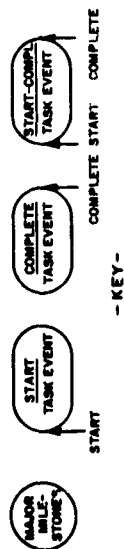
FIGURE 3.6. MAINTAINABILITY PROGRAM SCHEDULE PLAN
(PRODUCTION AND OPERATIONAL PHASES)

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of the three phases depicted in Figures 3.5 and 3.6, a
degree of scheduling flexibility must be recognized.   In
Phase I, however, a close adherence to a realistic schedule
is essential.   In this period of the program there is fre-
quently a tendency to defer the solution of the inevitable
problems until the time they arise.   This procedure en-
genders either excessive overtime or serious delay to the
program.   The objective of scheduling is to minimize these
conditions.

3.5.2 Research and Development Scheduling - A twelve month
period was allocated to accomplish the research and develop-
ment phase (See Figure 3.5).   During this period, the sev-
eral milestones or stages are presented from time of con-
tract award to delivery of the preproduction model.   The
required tasks are sequenced and show the associated tasks
are milestones to be satisfied before their own completion
can be accomplished; e.g., to accomplish the preliminary
design review task, which occurs during the third or
fourth month, it is essential that the maintainability
program plan and preliminary analysis and prediction are
completed. In addition, the human factors and design
trade-off tasks must supply certain inputs at this time.
Although not indicated on Figure 3.5, it is conceivable
that other factors may provide a useful input to the
design review task; such as, the mathematical model, the
specification review, and the design policy manual.   For
the purpose of this application, however, only the major
items have been indicated.   When planning a specific pro-
gram all inputs and outputs must be included.   There are
cases where some subsequent effort will continue although
completion is indicated.   For example, some additional
training of engineering personnel might be required after
completion of the training task.   However, in the schedule
this event is indicated completed becasue the major task
objectives have essentially been accomplished at that point.

3.5.3 Production Scheduling - The production phase is
described as a six month effort which begins with the
seventh month; coinciding with the research and develop-
ment phase and extending to the end of the twelfth month

(See Figure 3.6). According to this plan the first pro-
duction model will be delivered one month after the de-
livery of the preproduction model. All tasks are accomp-
lished in this time period except the evaluation and im-
provement task. If the program is a continuous one, this
task takes place as part of the research and development
phase.

3.5.4 Operational Scheduling - The operational phase is
described as a six month program which includes all mile-
stones, from installation of equipment through completion
of the maintainability program effort. This phase begins
at the start of the thirteenth month and extends to the
end of the eighteenth month. The evaluation and improve-
ment task takes place as part of the research and develop-
ment phase, providing the program is a continuous one.

4. DESIGN GUIDELINES

4.1 Scope

It is the purpose of this section to present a number of
design features important to system maintainability.
(The term system, includes the prime equipment, support
equipment, facilities, and maintenance personnel.) To
assist in judging the merits of alternate system configu-
rations, the relative importance of these design features
are given. A detailed review of each feature is provided,
permitting the full scope of each to be visualized. Appor-
tionment of design goals among sub-systems and equipment
sub-divisions is discussed. Finally the interaction be-
tween design, personnel, and support features are dis-
cussed.

4.1.1 System Design Apportionment - The system maintain-
ability goals must be apportioned among the three major
parameters (design, personnel, and support). To accom-
plish this a maintenance concept must be selected and a
mathematical model describing this concept developed.
Past experience with similar systems, together with the
data given in this section, may then be used to initially
apportion the overall goals to the major parameters. As
the design progresses, trade-offs among these parameters
may be effected using the data from this section and the
techniques given in Section 6, "Design Review," of this
report. Within the prime equipment design area the goals
may be further apportioned to the sub-system and component
levels.

4.1.2 Equipment Design Apportionment - The specification
of maintainability for subsystems of a complex system pre-
sents a difficult problem. The distributions observed
for down time have generally been log-normal. This dis-
tribution does not permit direct addition of repair rates
(reciprocal of mean down time) which is permissible with
the comparable failure rate used in reliability technology.
The following discussion reviews some of the problems in-
herent with combining or apportioning down time and pre-
sents a suggested approach.

4.1.2.1 Assume that an equipment was evaluated by sub-groups, the next problem is how to combine these partial figures for an overall measure of maintainability. Consider, for example, the equipment pictorially represented in Figure 4.1, "Equipment D." The portions of the diagram labeled A and B represent independent major functional units in Equipment D. Section C integrates the outputs of A and B. It is desirable to evaluate each section (A, B, and C) individually and combine the results into a total equipment requirement.

4.1.2.2 Sections A and B are considered independent of each other, hence, will be evaluated as two separate equipments following the method described in this text. If the desired figure of merit was mean down time, this would yield $\bar{M}_{ctA}$ and $\bar{M}_{ctB}$.

4.1.2.3 Section C is not independent, thus requiring a modified approach. Assume that Sections A and B are instantly replaceable modules, and evaluate the maintenance of Section C on this premise. Thus, Section C will be evaluated as though it contained the two major replaceable units A and B. This analysis will provide the contribution of C to the total maintenance requirement of D. The value of $(\bar{M}_{ct})$ for C was derived considering A and B instantly replaceable.

4.1.2.4 Since any maintenance of Equipment D will begin at Section C and proceed to either A or B, it is necessary to consider a method for combining the three figures derived. Symbolically, the problem can be represented as follows:

$$D = C \underset{B}{\overset{A}{\diagup\!\!\!\!\diagdown}} \tag{4.1}$$

Numerically, the problem can be stated as maintenance of D equaling C plus A or B. The probability of A or B is dependent upon their expected rate of failure. Thus, mean down time for Equipment D is expressed as follows:
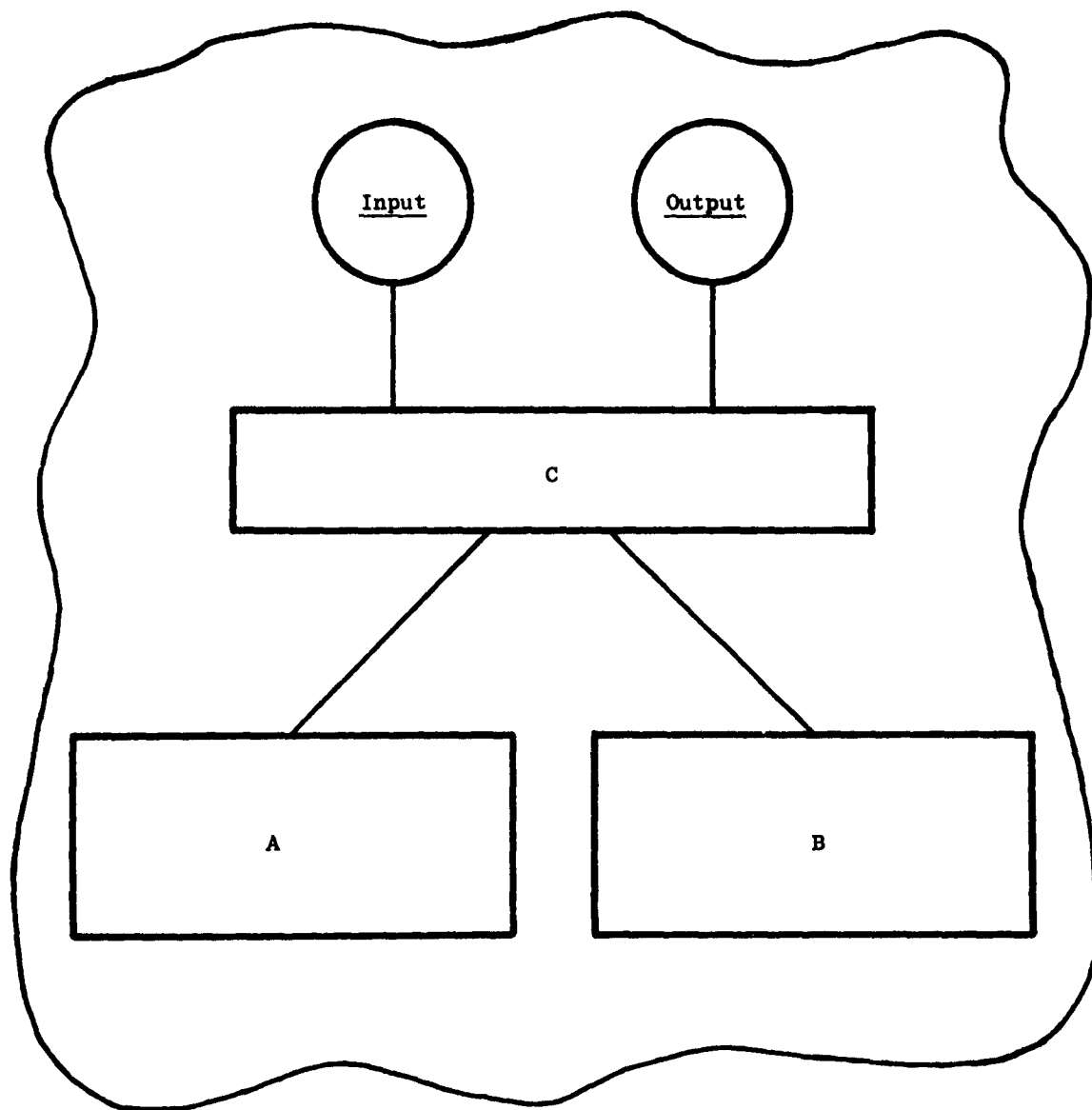
FIGURE 4.1.   EQUIPMENT D

$$\overline{M}_{ctD} = \overline{M}_{ctC} + \frac{\lambda A \ \overline{M}_{ctA} + \lambda B \ \overline{M}_{ctB}}{\lambda A + \lambda B} \qquad (4.2)$$

Where:

$$\lambda A, \ \lambda B = \frac{1}{MTBF_{(A,B)}} = \text{failure rate} \qquad (4.3)$$

Use of this technique requires strict adherence to stated assumptions, and is highly dependent upon carrying out detailed maintainability analysis. Further, it is dependent upon the distribution of each subsystem being similar. It is recognized that the model does not consider all ramifications of the problem but serves to formulate the general approach to be used in its solution.

4.1.3 <u>Use of Design Guidelines</u> - The guidelines presented in this section are basically for the purpose of providing the system/equipment designer with tools for designing maintainability into a system/equipment. They also provide information for improving a design or for effecting a trade-off. These guidelines are not inclusive and human factors or maintainability design handbooks (104, 105, 106, 107, 156) should be consulted for further information.

4.2 <u>Equipment Design Factors</u>

4.2.1 <u>Contribution to Down Time</u> - To design a maintainable equipment, it is necessary to know what features affect maintenance and what are the relative contribution of each. To make intelligent selection from alternate approaches, the impact of each on maintainability must be known; to improve equipment design, the areas most susceptible to improvement must be identified.

4.2.1.1 <u>Ordered List of Design Features</u> - By the use of maintenance data, the design checklists questions were ranked in accordance with their contribution to down time. The mathematical development was shown in the Phase IV report (4) and the resulting list is shown in Table 4.1, "Ordered List of Design Features." The validity of this list is based on the assumption that checklist question

TABLE 4.1

ORDERED LIST OF DESIGN FEATURES

	Design Features
Question Number	Title
B7	Assistance (Supervisors or Contract Personnel)
A1	Access (External)
A4	Access (Internal)
B1	External Test Equipment
B2	Connectors
A7	Visual Displays
A8	Fault Indicators
A9	Test Points (Availability)
A10	Test Points (Identification)
A11	Labelling
B3	Jigs or Fixtures
B6	*Assistance (Technical Personnel)
B4	*Visual Contact
B5	Assistance (Operations Personnel)
A3	Latches and Fasteners (Internal)
A5	Packaging
A15	Safety (Personnel)
A6	Units-Parts
A13	Testing (In Circuit)
A14	Protective Devices
A2	Latches and Fasteners (External)
A12	Adjustments
C2	Endurance and Energy
C3	Coordination, Manual Dexterity and Neatness
C4	Visual Acuity
C5	Logical Analysis
C9	Concentration, Persistence and Patience
C1	Arm, Leg, and Back Strength
C6	Memory
C8	Alertness, Cautiousness, and Accuracy
C10	Iniative and Incisiveness
C7	Planfulness and Resourcefulness

*Applies only to team tasks

down time element relations were judged correctly and that
questions relative to a particular time element are of
equal value. It is believed that equal values for questions
is a reasonable assumption for this analysis. With reali-
zation of these assumptions, it is felt that the result-
ing ordered list is useful in aiding design selection or
performing trade-offs. It must be noted that this list
was developed solely on down time considerations and
does not necessarily apply to cost of support or to
manning requirements.

4.2.2 <u>Equipment Design Guidelines</u> - The following para-
graphs present a detailed discussion regarding a number
of important maintainability design features. These
guidelines are not meant to be inclusive, and only the
most significant items gleaned from a literature search
and the data obtained in this program were included. The
items are grouped in accordance with the ordered list of
design features presented in Section 4.2.1. A descrip-
tion of the checklist questions is presented, plus no-
tation of a number of significant aspects pertaining to
each question. The final paragraph contains a list of
general features (which do not apply to any one parti-
cular group) for increasing maintainability. These fea-
tures were all considered to be very important, and should
be included in a design wherever practicable.

4.2.2.1 <u>Assistance (Supervisors or Contract Personnel)</u> -
This question determines the need for expert advice due
to the complexity of a particular task. The need for
simplicity applies here as well as sufficient displays
or performance indicators to ascertain the condition of
an equipment. The configuration of the equipment and
test point availability should be such that clear and
unambiguous indications of a malfunctioning unit are given.

4.2.2.2 <u>Access</u> - There were two questions dealing with
access, internal and external. These questions deter-
mined if the accesses were adequate for visual and mani-
pulative tasks. The following factors should be con-
sidered in design:

    a. Whenever possible, eliminate the need for access.

    b. Use pull-out drawers or racks whenever practicable.

    c. Use hinged doors instead of cover plates with
        fasteners.

    d. Provide adequate access to all test points, ad-
        justments, and replaceable parts.

    e. Determine if access is adequate by reference to
        human factors handbooks.

    f. Locate accesses so that they will not be blocked
        during the equipment installation.

    g. Remove all sharp edges and protrusions from accesses.

4.2.2.3 **External Test Equipment** - This question is con-
cerned with the number of pieces of test equipment needed
to accomplish a maintenance task. The following is a list
of design considerations that affect the need for, and
use of, external test equipment:

    a. Consider the use and limitations of standard test
        equipment when designing a circuit.

    b. Provide adequate means for connecting test equip-
        ment such as power receptacles and test jacks.

4.2.2.4 **Connectors** - This question deals with need for
special tools, fittings, or adapters for the use of
connectors with test equipment. The following items
should be considered when providing connectors:

    a. Use quick release connectors whenever possible.

    b. Provide enough space between connectors to permit
        a firm grip for connecting and disconnecting.

    c. Select connectors so that there is no need for
        special tools or adapters.

    d. Key connectors so that a wrong connection between
        plugs and jacks cannot be made.

    e. Always use connectors instead of directly in-
        stalled cables external to the equipment.

4.2.2.5 **Visual Displays** - This question is concerned with
the number of display areas that have to be consulted to
gain sufficient information to perform a maintenance task.

The following is a list of important items to consider when designing displays:

    a. Make maximum possible usage of operational displays as maintenance aids by insertion of test data through switching.

    b. Locate all maintenance displays so that they can be observed from one position.

    c. Locate all displays so that they can be observed with no disassembly or removal of equipment.

    d. All-or-none displays should be used where they will convey sufficient information.

    e. Label displays to indicate functional quantity measured.

    f. Instrument scales should contain only the information needed for a maintenance technician to make a decision.

4.2.2.6 Fault Indicators - This question is concerned with the adequacy of fault and operation indicators or built-in test equipment. The items listed for visual displays are applicable here as well as the following:

    a. Provide sufficient indicators for accurate and easy determination of equipment performance.

    b. Use go-no-go indicators wherever possible.

    c. Provide auditory signals to supplement fault indicators for equipment failure.

    d. Make maximum use of built-in test equipment consistent with the overall maintenance concept.

    e. Built-in signal injection devices and self-testing features should be included whenever practicable.

4.2.2.7 <u>Test Points</u> - There are two questions dealing with test points, availability and identification. The following features should be considered in the selection and placement of test points:

    a. Provide test points to measure the input and output of every circuit.

    b. Locate test points in groups and arrange them conveniently for sequential checking.

    c. Label each test point with a symbol designating the function measured and paint with an outstanding color (luminescent preferred).

    d. Determine realistic voltages and wave shapes for test points, including ranges for satisfactory operation. This information should be provided at the test point location whenever practicable.

    e. Mount terminal boards in accessible positions and identify connections for use as test points.

4.2.2.8 <u>Labeling</u> - This question is concerned with the manner in which parts are labeled and the amount of information supplied. The following rules should be followed for part labeling:

    a. Label all parts with complete identifying information

    b. Place part labels so that they are clearly visible.

4.2.2.9 <u>Jigs or Fixtures</u> - This question deals with the need for special tools or test fixtures. The requirements for such items should be eliminated if at all possible. If they are deemed necessary, they should be designed for easy and accurate use and be located close to the area where needed.

4.2.2.10 <u>Technical Assistance</u> - This question is concerned with the number of personnel necessary to complete a task. This number can be kept to a minimum by following these rules:

a. Provide for positive connection of test leads to test points.

b. Place displays and adjustments so that they can both be seen from the same position.

c. Limit the weight of replaceable units to 40 pounds.

d. Simplify maintenance actions.

4.2.2.11 Visual Contact - This question determines if the activities of one member are visable to the other in team actions. The important considerations in this area are to preclude the need for more than one maintenance technician to perform tasks and to keep all maintenance displays and accesses on one side of the equipment.

4.2.2.12 Assistance (Operations Personnel) - This question determines the amount of consultation with operations personnel required to complete a maintenance task. The prime need in this area is adequate operational displays that give clear indications of equipment performance.

4.2.2.13 Latches and Fasteners (Internal) - This question determines whether latches and fasteners are captive, needed no special tools, and required only a fraction of a turn to release. The following items should be considered when providing for latches and fasteners:

a. They should be captive whenever possible.

b. They should not require special tools.

c. They should require only a fraction of a turn to release or, if bolts are used, the number of turns required should be kept to a minimum.

d. Limit the number of fasteners to as few as possible.

e. Minimize the number of types and sizes used in an equipment.

  f. Use hand-operated fasteners when possible.

  g. If bolts are used, the heads should be hexagonal
    and have deep internal slots.

  h. All set-screws should have the same type and size head.

4.2.2.14 <u>Packaging</u> - This question deals with whether
or not internal access can be made to components and parts
without mechanical disassembly. The following items
should be considered in packaging the equipment:

  a. The items listed under access.

  b. Provide sufficient room for maintenance.

  c. Do not stack parts on top of one another.

  d. Locate small parts so that large or heavy parts
    do not prevent access to them.

  e. Develop an overall packaging concept that will
    allow the removal of a replaceable assembly or
    part without removing any other.

4.2.2.15 <u>Safety (Personnel)</u> - This question determines
if maintenance personnel are required to work in close
proximity to hazardous conditions (high voltage, radi-
ation, moving parts, and high-temperature parts). Ade-
quate protection from such hazards (interlocks, shield,
warning indicators, and shorting bars) must be provided.

4.2.2.16 <u>Units-Parts</u> - This question deals with the
nature in which replaceable units or parts are mounted.
The following criteria should be followed:

  a. Use plug-in assembly where possible.

  b. Consider modularization to ease replacement.

  c. Design for maximum interchangeability between
    units and parts.

4.2.2.17 Testing (In Circuit) - This question determines whether or not a defective part or component can be tested without removal from the circuit. The equipment should be designed so that parts can be tested without removal from the circuit; if this is not possible, such parts should be easily removable.

4.2.2.18 Protective Devices - Protective devices should be incorporated in all circuits where further damage may be incurred in case of a malfunction. This includes circuit breakers, fuses, and fail-safe circuitry.

4.2.2.19 Latches and Fasteners (External) - The same criteria applies as in paragraph 4.2.2.13 (Latches and Fasteners - Internal) above.

4.2.2.20 Adjustments - This question determines the number of adjustments or alignments necessary to place an equipment back in operation. The following features should be considered when providing for adjustments:

    a. Use stable circuitry so that the necessity for peaking is eliminated.

    b. Design the equipment so that components can be replaced without the need for readjustment.

    c. There should be no interaction between adjustments.

    d. A clockwise adjustment should produce an increasing value and vice-versa.

    e. Label all adjustments and provide indexing.

    f. Use knobs instead of screwdriver slots where possible.

4.2.2.21 Endurance and Energy - This question refers to the degree of sustained physical effort required to complete a maintenance action. Here again, simplicity is the most important consideration. Minimum requirements for

assembly and disassembly and the movement of heavy components will reduce the need for physical effort.

4.2.2.22 Eye-Hand Coordination, Manual Dexterity, and Neatness - This question is a composite of three associated personnel requirements. Eye-hand coordination refers to any act involving the use of the eyes while manipulating the hands to accomplish the same action. Manual dexterity refers to the skill required when using the hands to accomplish an action. Neatness applies to the need for tidiness to adequately accomplish a task. The design requirements in this case, are to eliminate, wherever possible, the requirements for the above actions. One important consideration is to make control-display combinations so that a clockwise adjustment results in an increasing value and vice-versa.

4.2.2.23 Visual Acuity - This question deals with the preciseness of visual acuity necessary in performing maintenance. The important features to consider here are adequate displays, readable scales, labeling, and color coding. Also, provision must be made for sufficient lighting to adequately perform maintenance.

4.2.2.24 Logical Analysis - This question deals with the amount of mental reasoning necessary to determine the origin of a malfunction. The following features will decrease the requirement for logical analysis:

    a.   Units should be able to be checked independently.

    b.   Group circuits so that a minimum of crisscrossing of signals between units is required.

    c.   Modules should have as few input and output signals as possible.

    d.   Avoid trick or extremely sensitive circuitry; use standard circuits.

    e.   Separate operational circuitry from maintenance circuitry.

    f.   Design for maximum use of maintenance aids (trouble-shooting procedures, maintenance diagrams, and circuit data).

    g.   Develop maintenance procedures concurrent with equipment design.

4.2.2.25 <u>Concentration, Persistance, and Patience</u> - This is a composite of three questions which deals with the perserverance necessary to complete maintenance actions. The use of simple circuitry, adequate test points, and unambiguous displays will minimize this requirement.

4.2.2.26 <u>Arm, Leg, and Back Strength</u> - This question deals with the amount of physical effort required of the maintenance technician. The designer must always keep in mind the average physical capabilities of male human beings. These capabilities can be found in human factors handbooks.[104,105,106] Where maintenance personnel are required to move heavy objects, adequate provision must be made for ease of handling.

4.2.2.27 <u>Memory</u> - This question deals with the degree to which maintenance actions required a previous knowledge of the equipment. The design considerations for this category are to make the equipment as simple as possible and insure that all needed information is included in maintenance manuals. An important consideration here is the use of standard circuits wherever possible.

4.2.2.28 <u>Alertness, Cautiousness, and Accuracy</u> - This is a composite question dealing with the requirements for care and forethought necessary in performing maintenance. The prime requirements here are to provide adequate maintenance procedures and to provide adequate protection from human error in these procedures.

4.2.2.29 <u>Initiative and Incisiveness</u> - This question deals with the need for the understanding of maintenance tasks in order to determine a course of action, and to introduce a new measure when a previous course has failed.

This again requires circuit and functional simplicity, as well as clear and unambiguous displays and test-point readings.

4.2.2.30 <u>Planfulness and Resourcefulness</u> - This question considers the importance of the need for careful planning and use of ingenuity in carrying out maintenance. The designer must always consider the complexity of the maintenance task dictated by a particular circuit design or configuration. A circuit should always be designed so that a simple routine can be followed to check it out.

4.2.2.31 <u>Miscellaneous</u> - The following general features should be considered during equipment design:

    a.   Provide efficient maintenance aids (diagrams, maintenance instructions, test-point data, and built-in test equipment.)

    b.   Provide for marginal testing when consistent with the overall maintenance philosophy.

    c.   Design for the effective installation of the equipment.

    d.   Use standard parts to the maximum possible extent.

    e.   Use color-coding where feasible.

    f.   Orient tube sockets with pin gaps or keys facing in the same direction.

4.3 Personnel Factors

4.3.1 <u>Maintenance Personnel Contribution</u> - The personnel parameter has a demonstrated effect on maintainability but the multiplicity of factors creates difficulty in their isolation and measurement. It has been observed that maintenance personnel do vary widely in their speed and accuracy in performing maintenance. So far, attempts to determine the basic reasons for this variance have not been successful. This research has, however, given a good insight into the average abilities of maintenance personnel. This information is useful for designing an

equipment and permits utilization of available skills and the selection of personnel to maintain a particular system or equipment.

4.3.2 **The Average Maintenance Man** - The personnel data gathered during this research were analyzed to determine the average characteristics of personnel performing maintenance on Air Force ground electronic equipment. The results show the average technician is 23 years old, and a high school graduate with an aptitude for electronics. He has had approximately 22 weeks of military training on electronic fundamentals and specialized equipment. In addition, he has had approximately 12 months of actual maintenance experience and has attained a 5 level of proficiency.

4.4 Support Factors

4.4.1 **Contribution to Down Time** - The environment in which a system/equipment is maintained has a direct effect on the time to perform maintenance. The factors of this environment include the natural environment (temperature, humidity, etc.), logistics, maintenance facilities, test equipment and tools, maintenance organization, and technical data. These factors are generally considered not to be within the purview of the equipment designer, but the designer can directly effect elements of these factors, and he can tailor his design to meet the requirements imposed by these factors.

4.4.1.1 **Support Checklists** - The checklists developed in the course of this study to measure the support factors have been found to be significantly related compositely to equipment down time. Accordingly, the questions contained form the basis for evaluating system support characteristics. The individual checklists were analyzed individually but an ordered rank of importance could not be established. Details concerning this analysis are contained in Section 3, Volume I, of this report.

4.4.2 <u>Support Design Guidelines</u> - The following paragraphs present guidelines to assist in designing a support system. A number of the features presented are also directly applicable to the prime equipment design. The questions from the support checklists, that were found to contribute to down time, are used as the basic guidelines. The intent of each question is described and its effect on design given. Some of the checklist questions that are not applicable to the design area may be affected by the selection of the over all maintenance philosophy.

4.4.2.1 <u>Manuals, Technical Orders and Instructions</u> - This checklist deals with the condition and the adequacy of the technical data required to perform maintenance. The availability of the data is also considered but this is beyond the control of the designer. A description of each checklist question is given in the following paragraphs.

4.4.2.1.1 <u>Availability of Manuals, Technical Orders and Instructions</u> - This question determines if the manuals and instructions necessary for a particular maintenance task are available for use by the maintenance personnel. This cannot be controlled by designer, but it should be noted that technical data are necessary for the performance of maintenance.

4.4.2.1.2 <u>Clarity of Manuals, Technical Orders and/or Instructions</u> - This question determines if the technical data contains an adequate description of the maintenance procedures to be followed, and if these procedures are presented in a clear and concise manner. It is important that concurrent with equipment design, maintenance manuals be developed that describe all maintenance procedures. These manuals should be readily understood by the average maintenance man, and should require a minimum of cross referencing between manuals or sections of manuals.

4.4.2.1.3 <u>Accuracy of Technical Orders and/or Instructions</u> This question deals with the accuracy of the technical data required to perform maintenance. It is very important that the data supplied with an equipment reflect the actual configuration of the equipment and are completely accurate. When modifications are performed on an equipment, revised

data should be supplied with the modification to update the existing technical manuals.

4.4.2.1.4 Completeness of Technical Orders and/or Instructions - This question is concerned with signal characteristics and tolerances. Included in the technical data supplied with an equipment, should be accurate descriptions of the signal characteristics together with the variations to be expected in normal operation, for each test point.

4.4.2.1.5 Availability of Schematics and Circuit Diagrams This question determines if the diagrams necessary for a particular maintenance task are available for use by the maintenance personnel. This is not an area that can be controlled by the designer but shows that such diagrams are necessary for the performance of maintenance.

4.4.2.1.6 Accuracy of Schematics and/or Circuit Diagrams This question deals with the accuracy of the diagrams required to perform maintenance. The schematics and circuit diagrams supplied with an equipment should be accurate in every detail and reflect the actual configuration of the equipment as delivered. When modifications are performed on an equipment, revised diagrams should be supplied with the modification to replace the existing ones.

4.4.2.1.7 Completeness of Schematics and/or Circuit Diagrams - This question is concerned with signal characteristics and tolerances shown on the maintenance diagrams. Whenever possible signal characteristics together with the variations that occur during normal operation, should be shown on schematics and circuit diagrams. These characteristics should be shown for each test point and should be accurate.

4.4.2.1.8 Presentation - This question deals with the manner in which checkout procedures and the associated minimum performance standards are presented in the maintenance manual. Each checkout procedure together with the required minimum performance standards, should be presented clearly in a single section of the manual. The performance standards

should be such that the required mission can be performed whenever the equipment exceeds the stated values.

4.4.2.1.9 Maintenance Aids - This question determines if maintenance aids are supplied in addition to the normal technical data and diagrams. Whenever possible, maintenace aids should be developed to assist in the performance of maintenance. Examples of such aids follow:

a. Signal flow diagrams,
b. Diagnostic procedures,
c. Pictorial representations of the equipment,
d. Circuit board overlays, and
e. Card file systems.

4.4.2.1.10 Up-Dating - This question determines if all modification data are available to the maintenance technician. As mentioned in previous paragraphs, all modifications should be accompanied with revised maintenance data and diagrams.

4.4.2.2 Supply Conditions - This checklist deals with the condition of the supply system that supports the maintenance organization. In general the supply system cannot be changed by the designer but the requirements for supply can. Also, an equipment may be designed to be compatable with the programmed supply system. A description of each checklist question is given in the following paragraphs.

4.4.2.2.1 Accessibility - This question determines the time required to secure replacement parts. Although this area is not within the purview of the equipment designer, the number of replacements required may be reduced through equipment design which presents clear and unambiguous malfunction symptoms and test point readings. Supply time may also be reduced by keeping the number of different types of parts required to a minimum, and by maximum use of standard parts.

4.4.2.2.2 Acceptability - This question determines if the characteristics of the replacement part are suitable for the intended purpose. This problem may be reduced by minimizing the number of different types of spare parts required and by reducing the number of non-standard parts.

4.4.2.2.3 <u>Relative Location</u> - This question deals with the location of the supply area relative to the maintenance area. The comments given in paragraph 4.4.2.2.1 are applicable to this question.

4.4.2.2.4 <u>Packing</u> - This question determines the time spent unpacking the new part and/or repacking the replaced part. The support system designer should take this requirement into consideration when specifying packaging and supply handling methods. The equipment designer may affect this area by keeping spares requirements to a minimum.

4.4.2.2.5 <u>Auxiliary Materials</u> - This question determines the time required to obtain auxiliary materials (cleaning fluids, solder, wire, etc.). This area is not within the purview of the equipment or support system designer.

4.4.2.2.6 <u>Parts Identification</u> - This question determines the time required to obtain the stock number for the required parts. A cross reference between circuit symbol designation and federal stock number should be included in the maintenance manuals supplied with the prime equipment.

4.4.2.2.7 <u>Supply Forms</u> - This question determines the time required to complete supply forms to obtain replacement parts. This requirement may be reduced by keeping spares requirements to a minimum.

4.4.2.2.8 <u>Local Bench</u> - This question determines if the replacement part was available from the local bench stock. The support system designer should determine the high usage parts and specify that they be provisioned for local bench stock. If the number of types of spares are kept to a minimum, the balance of the spares should be available through normal supply channels.

4.4.2.2.9 <u>Tools</u> - This function deals with the location of the tools necessary to perform a maintenance task. The equipment designer should minimize special tools requirements. If the use of special tools is unavoidable they should be stored in the equipment adjacent to the area where they are required.

4.4.2.2.10 <u>Supply Coordination</u> - This question determines if contact is required with supply personnel. This area is not within the purview of the equipment or support system designer.

4.4.2.3 <u>Test Equipment and Tools</u> - This checklist deals with the availability, condition, and suitability of the test equipment and tools required to perform maintenance. This area constitutes the major contribution of the support system designer. All of the items of this checklist must be considered when selecting the maintenance concept. The equipment designer, in turn, should design the prime equipment so that the requirements for test equipment and tools are minimized, and so that standard items may be used wherever possible. A description of each checklist question is given in the following paragraphs.

4.4.2.3.1 <u>Availability (Bench Type)</u> - This question determines if the required bench test equipment and accessories needed to perform a maintenance task are available. The support system designer should specify standard test equipment whenever possible, and the required equipment should be specified as early as possible in the procurement cycle to insure availability in the field.

4.4.2.3.2 <u>Availability (Portable Type)</u> - This question is the same as 4.4.2.3.1 except that portable equipment is considered.

4.4.2.3.3 <u>Operating Condition</u> - This question determines if the required test equipment is in good operating condition and is within its calibration period. Reduction in the amount of different test equipment required will increase the probability that it will be maintained in good operating condition.

4.4.2.3.4 <u>Preparation</u> - This question determines the amount of set-up time for the required test equipment. If new test equipment is designed for a particular system, one design goal should be minimum set-up and warm-up time.

4.4.2.3.5 <u>Tools (Standard)</u> - This question deals with the availability and condition of the required standard tools. Reduction in the amount of different tools required will increase the probability that they will be on hand and in good condition when needed.

4.4.2.3.6 <u>Tools (Special Type)</u> - This question deals with the availability and condition of the required special tools. The requirement for special tools should be kept to a minimum. They should be stored in the equipment whenever possible to insure availability.

4.4.2.3.7 <u>Test Equipment Capabilities</u> - This question determines if the test equipment is capable of providing all the information necessary to perform a maintenance task. It is important that test equipment be specified that is capable of performing all needed tasks to maintain the prime equipment. The equipment designer should design the prime equipment to utilize the capabilities of standard test equipment.

4.4.2.3.8 <u>Manuals</u> - This question determines if handbooks and/or instructions are available for the required test equipment. This is not with the purview of the equipment or support system designer but shows that such instructions are required.

4.4.2.3.9 <u>Handling</u> - This question determines whether portable test equipment is either less than 35 pounds in weight, or is provided with a cart. Portable test equipment should be as light as possible. If it is necessary that a heavy piece of equipment be portable it should be provided with a dolly.

4.4.2.3.10 <u>Calibration</u> - This question determines if the calibration controls on the required test equipment are physically separated from the controls used for operation. If new test equipment is designed for a system, the calibration controls should be separated from the operation controls so that the calibration will not be accidently upset during tests.

4.4.2.3.11 Presentations - This question determines if the
test equipment indications are easily read by the technician
performing the maintenance task. Test equipment indications
should be clear and definite and be visible to the technician
performing the test.

4.4.2.3.12 Conversion Factor - This question determines if
conversion of test equipment indications is necessary. Test
equipment should be provided which may be read directly in
units that are meaningful to the test being performed. If
conversion is necessary, charts which allow for quick con-
version of the test data should be permanently attached to
the test equipment.

4.4.2.3.13 Automatic Qualities - This question determines
the number of operational adjustments necessary to utilize
the required test equipment. Test equipment should be pro-
vided which requires no operational adjustment. If adjust-
ments are necessary, they should be kept to a minimum.

4.5 Factor Integration

4.5.1 Balancing Physical Design Against Support - The
previous discussion of the support parameter checklist questions
has shown that, in general, these areas affect both prime
equipment and support system design. The information supplied
in the design guidelines can be used to balance the main-
tainability requirements between the prime equipment and
the support system. The basic maintenance concept should
consider the interactions between physical design and
support. This maintenance concept then provides the frame-
work within which trade-offs may be made.

4.5.2 Design Trade-offs - The design guidelines given in this
section provide tools for performing design trade-offs between
the maintainability parameters (design, personnel, and support),
and other system parameters. Section 6 of this report gives
some techniques for performing these trade-offs.

5. APPLICATION OF THE PREDICTION TECHNIQUE

5.1 General Approach

The maintainability prediction technique for evaluation of electronic equipment is accomplished in four steps as follows:

a. Selection of sample size
b. Determination of task sample
c. Task prediction
d. Calculation of maintenance indices

Briefly the statistical selection of a sample of failed parts/components; and the quantitative evaluation of the contribution that each assumed failure makes to the total equipment maintenance time, permits the calculation of the overall equipment mean down time. The justification for, and the steps involved in, determining the total down time, are given in detail in the text that follows. The use of this method permits the calculation of an accurate system maintainability figure, without requiring the time consuming empirical evaluation of the maintainability of each part/component in a complex electronic system. Detailed explanations for each of those steps, plus illustrative examples of the process, are contained in the following paragraphs.

5.2 Selection of Sample Size - The sample size to be used in the prediction is dependent upon the statistical accuracy desired. With stated accuracy requirements (k) and desired confidence level, the sample size (N) which satisfies these requirements is computed as follows:

$$N = [\frac{\phi \sigma}{k \bar{X}}]^2 \qquad (5.1)$$

Where:

ϕ = Confidence level
σ = Population variance
$\bar{X}$ = Population mean
k = Accuracy

5.2.1 This equation was solved for a number of values.
The results are shown in Figure 5.1, "Sample Size Nomo-
graph." (4)   The coefficient of variation ($\sigma/\bar{X}$) was
plotted against sample size for various levels of
accuracy (k) at 90% confidence level (ϕ).

5.2.1.1 The observed field data provides a basis for
determining the sample size needed for a typical prediction
problem. The ratio of $\sigma/\bar{X}$ for the field data was found
to be 1.07. For example, a sample size of 50 will permit
stating the mean with an accuracy of ± 25%, with a con-
fidence of 90%.

5.2.1.2 The confidence level is a measure of the pro-
bability that the true mean of the population, estimated
by calculating the mean of the sample, lies within the
confidence interval, specified by multiples of the standard
error ($\sigma/\sqrt{N}$). A statement of 90% confidence level
implies that their is a 90% probability (± $1.645\sigma/\sqrt{N}$) of
the sample interval including the true mean. The confi-
dence interval is also a function of the accuracy desired.
For example, if it were desired to state the mean with
an accuracy of 10% the 90% confidence interval for an
expected mean of 50 minutes would be ± 5 minutes.
The upper and lower confidence limits would be 55 and 45
minutes respectively with a confidence interval of 10
minutes. It must be recognized that in selecting a sample,
the ratio $\sigma/\bar{X}$ must be approximated before the actual
value is known. After the sample has been taken, it
may be found that the actual value differs. Since the
actual confidence interval depends upon the sample data,
re-calculation of these levels may dictate additional
samples to be taken to acquire accuracy desired.
Accordingly, it is desirable to plan pessimistically
to assure that the sample size will fulfill requirements.

5.3   Determination of Task Sample

5.3.1 General Considerations - The application of the
prediction technique during the various phases of equip-
ment development basically involves the evaluation of
hypothetical part failures as maintenance tasks. Through
the consideration of various factors associated with the
failure and replacement of these parts, the maintenance
capability of the equipment can be predicted. The main-
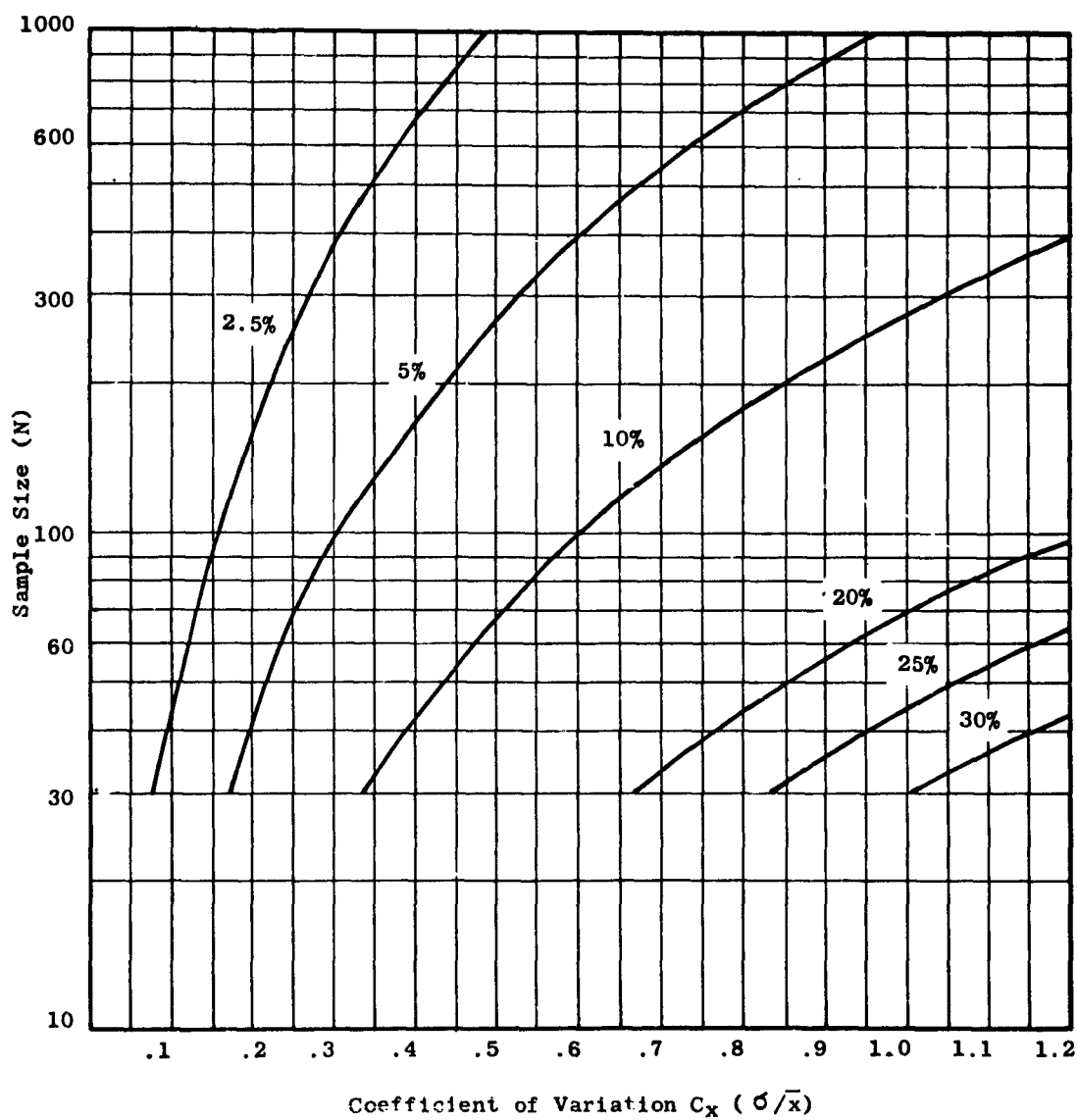
FIGURE 5.1. SAMPLE SIZE NOMOGRAPH

tenance time thus derived is an estimate of the average time to accomplish a maintenance task under actual operational conditions.

5.3.1.1 With the complexity of equipments now appearing in the field, evaluation of each part in respect to its contribution to maintenance time would not be practical, nor is it necessary. For example, the AN/FPS-20 radar has over 10,000 active electronic parts. Since the physical arrangement and function of many of these parts are similar in respect to a maintenance task, it is only necessary to select parts which will, on the average, be representative of maintenance tasks which can be expected to occur under operational conditions. Such a sample from an equipment will permit its maintainability to be accurately predicted.

5.3.1.2 The distribution of the sample among part classes and among areas of the equipment should be representative of that which would occur during field operation. Relaibility data can be used to determine the failure distribution among the part classes. Random assignment of individual parts within part classes will distribute the sample among the equipment areas in accordance with their relative populations.

5.3.2 Selection Technique - The process of task selection will be illustrated by means of an example. Essentially, two basic ingredients are required to determine the parts to be used for tasks: (1) number of parts by class in the equipment (part complexity), and (2) the predicted average failure rate of each part class. The AN/FPS-20 will be used to illustrate the steps involved. The equipment has two identical channels; therefore, evaluation of one channel will be sufficient because maintenance actions due to a particular part failure will be identical in either channel. Part reliability data for this illustration were obtained from previous field evaluations. [153] In actual practice, reliability data may be obtained from a prediction performed for the equipment being analyzed, from published average failure rates for part types, or from field data on similar type equipments.

5.3.2.1 Table 5.1, "AN/FPS-20 Part and Failure Distribution," summarizes the data. Here are listed the number of parts, average failure rates, and the expected number of failures for one thousand hours of equipment operation. From the expected number of failures (Table 5.1), the percent contribution of each part class to the total expected failures was computed. The actual number of parts for each class was then determined for a sample size of 50. Table 5.2 "AN/FPS-20 Part Class Sample Size," shows the tabulated data. Note that tubes contribute approximately 82% of the expected number of failures. Tubes, therefore, accounted for 41 of the maintenance tasks (82% of 50). The number of remaining tasks were determined in a similar manner.

5.3.2.2 After determining the distribution of the desired sample, it is necessary to select actual parts from the equipment to use as simulated maintenance tasks. This can be accomplished by coding the parts and using a random selection technique such as a table of random numbers to select the desired number of parts in each class.

5.3.2.3 To simulate maintenance tasks with the selected parts, it is necessary to assume that each part fails in some manner. The next task, then, is to select the mode of failure to be used for each part. This can be accomplished in a number of ways; i.e., random assignment, select the most probable, or assignment in accordance with the frequency of occurrance for each mode. In random assignment the tasks for each class are distributed evenly among the possible failure modes. The most probable method is the selection of the way in which a part fails most often in its particular application. If a failure mode analysis has been performed for the equipment, the failure modes may be assigned in accordance with the expected failure rates for each mode. The selection of the method of assignment is based on the particular configuration of the equipment under study and the amount of information available. In many cases the mode of failure has a negligiable effect on the resulting down time but in some cases there may be a wide variance between modes. The selected parts should be carefully analyzed to determine if the latter case exists.

TABLE 5.1

AN/FPS-20 PART AND FAILURE DISTRIBUTION

Part Class	Quantity (Single Channel)	Average Part Failure Rate 1000 Hours	Number of Expected Failures per 1000 Hrs.
Motor	25	.00189	.04725
Capacitor	1280	.00010	.12800
Diode	4	.02983	.11932
Connector	335	.00032	.10720
Relay	43	.00359	.15437
Coil	349	.00033	.11517
Resistor	2459	.00015	.36885
Switch	162	.00045	.07290
Transformer	160	.00133	.21280
Tube	380	.01567	5.95460
Total	5197		7.28046

TABLE 5.2

AN/FPS-20 PART CLASS SAMPLE SIZE

Part	Contribution to Total Expected Failures (%)	No. of Failures for Sample Size of 50	Actual Sample Used
Motor	.65	.3	0
Capacitor	1.76	.9	1
Diode	1.64	.8	1
Connector	1.47	.9	1
Relay	2.12	1.1	1
Coil	1.58	.8	1
Resistor	5.07	2.5	2
Switch	1.00	.5	1
Transformer	2.92	1.3	1
Tube	81.79	40.9	41
Total	100%		50

5.4 Task Prediction

5.4.1 Information Required - To accomplish the task pre-
dictions, the evaluator should have available detailed
information including schematic diagrams and physical
layouts. The evaluator must be thoroughly familiar with
the functional operation of the equipment. Other infor-
mation needed is a description of the tools and test
equipment to be provided and the maintenance aids to be in-
corporated in the prime equipment. A description of the
operation and maintenance environment is also extremely
valuable. Figure 5.2, "Maintainability Prediction Form,"
has been developed to facilitate the maintenance analysis
and task scoring. On this form, specific information re-
quired to complete task prediction is listed along with
identification data regarding equipment, evaluator, etc.

5.4.2 Maintenance Analysis - Prior to task scoring, it
is necessary that, for each task, a maintenance analysis be
performed. This analysis entails a step-by-step accounting
of a logical diagnostic procedure. Beginning with the
symptoms of malfunction, each step required in locating
the defective part is recorded. Complementary to each step,
notations regarding access problems, test equipment re-
quirements, and related information which is important to
determining the task scores, are made. Figure 5.3,
"Maintenance Analysis Continuation Sheet," illustrates a
format used for this analysis. The form is divided into
two columns. The left column, labeled "Maintenance Steps"
is used to record each test or step that a technician
should make. Scoring comments associated with each step
are entered in the column on the right. Completion of
the maintenance analysis provides a firm basis for the
scoring. The full scope of a maintenance situation is
realized through this process.

5.4.2.1 This analysis may be facilitated by the prepara-
tion of a, "System Maintenance Diagram," which would
clearly detail the system functional block diagram, with
main signal paths major test points and other diagnostic
aids shown. An illustration of such a diagram is shown
in Figure 5.4, "Maintenance Diagram AN/GRT-3." This

Equip. _____ Unit/Part_____ Task No. _____

Ass'y. _____ By _____ Date _____

Primary function failed unit/part _____

Mode of failure _____ _____

Malfunction symptoms _____ _____

Maintenance Analysis

Maintenance Steps	Scoring Comments

Checklist Scores

	1	2	3	4	5	6	7	8	9	10	11	12	13	1 4	15	Total
A																
B																
C																

Predicted down time . . . . _____ Min.

FIGURE 5.2. MAINTAINABILITY PREDICTION FORM

MAINTENANCE ANALYSIS CONTINUATION SHEET

Equip._____   Part_____   Task No._____

Maintenance Steps	Scoring Comments

FIGURE 5.3, MAINTENANCE ANALYSIS CONTINUATION SHEET

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TRANSMITTER

MODULATOR-POWER SUPPLY

Metering Circuits

Trippler-Driver +850 +250

Exciter (Crystal freq.=f) +300 +250 -100 -35

12f

-100 ①

Side Tone Out

④ ③ ② ①

Ⓜ2 Ⓜ1

36f

R.F. Sample ⑤

Antenna Coupling Circuits

R.F.

Antenna Xmitt.-Receive

Modulated R.F. (36f)

Power Amplifier A.F. +190 V.D.C. ③ -60

Screen Modulator +850 +250

A.F. +850 V.D.C.

Modulator Driver ⊙ J-305 A.F. (Push-Pull)

Plate Modulator J-306 ⊙ +850

High Voltage Supply +850 H.V. on-off +300 Fil. on-off +250

Low Voltage Supply L.V. on-off Fil. on-off

A.F. (Push-Pull) +250 ⊙ J-304 Control Bias -100

A.P. Amplifier -65 J-303 ⊙

A.F. Sample

Modulation Limiter J-307 ⊙ +250 J-302 ⊙ Muting

Control Circuits Fil. on-off L.V.&H.V. on-off Antenna Xmitt-Rec'v -65 -100 -100 -60 -15

Bias Supply Fil. on-off

Narrow Wide Band A.F. In

Control Switches A.C. In

L E G E N D

① Osc.grid current - 2nd doubler grid current - buffer grid current- buffer plate current
② Driver grid current - driver plate current
③ Power amp. grid current - driver plate current
④ J-302, 303, 304, 305, 307 J-804, 806, 807, 808 (Modulator Voltages) (Transmitter Voltages)
⑤ R.F. Power - % modulation

FIGURE 5.4. MAINTENANCE DIAGRAM AN/GRT-3

diagram assists in the determination of the malfunction symptoms and in selecting steps to isolate the malfunction to a functional area. It is necessary to have a schematic diagram for each block to trouble-shoot within a block and to determine the effect of an assumed failure on the output(s) of other blocks. The illustrated diagram is representative of the minimum requirements for such a diagram and may be expanded to varying degrees depending on the complexity of the equipment and the information available.

5.4.2.2 Analysis Example - The use of the maintenance analysis procedures described in a preceding paragraph will be illustrated by evaluating the time requirements for a specific task. Resistor R-7801, appearing in Amplifier Mixer AM-1347/FPS-20 of the Radar AN/FPS-20, has been selected for this purpose. The following discussion illustrates the procedure to be followed.

5.4.2.2.1 Evaluation of Resistor Failure - The resistor failure was assumed to have occurred by opening. Following this assumption, a step-by-step maintenance analysis was made, drawing from both general maintenance experience and technical data. [152] This procedure is illustrated in Table 5.3, "Maintenance Analysis, R-7801/FPS-20." Here the detailed steps necessary to isolate the defective resistor are listed. For each step, comments regarding availability of test indicators, need for test equipment, access problems, and related information needed to effectively score this task were listed. Figure 5.5, "AN/FPS-20, Transmitting System," illustrates functionally the major circuits associated with the transmitter section. Within the diagram each step has been numerically identified. It will be noted that the troubleshooting path chosen is one of several possible routes. The route established was based on the importance of the check and the ease with which it could be taken. For example, in step 2, the trigger input which is vital for the proper operation of three portions of the transmitter, was tested. The third step was selected because of the ease with which the information could be secured (built-in metering). Such choices are generally consistent with procedures employed by electronic technicians.

TABLE 5.3

MAINTENANCE ANALYSIS, R-7801/FPS-20

Maintenance Analysis Continuation Sheet	
Equipment **AN/FPS-20**　　Part **R-7801/FPS-20**　　Task No. **1**	
Maintenance Steps	Scoring Comments
1.　Equipment malfunction is initially indicated by no target returns on indicator. Maintenance action proceeds to isolate trouble to major equipment functions. Power output check at bidirectional coupler (CU-516) isolates trouble to transmitter function.	Radio Frequency Monitor (I D-446) normally connected to system is used to monitor power output at bidirectional coupler (CU-516). Test equipment serves variety of tests for equipment adjustment and repair. Preliminary calibration or test set-up may be required. Proper values listed in T.O.
2.　Trigger pulse is checked at I PA Modulator (MD-276) to isolate trouble to transmitter or modulator unit of the transmitter section. Presence or trigger indicates trouble in R.F. generating stages (Stalo, Buffer Amplifier, Mixer, or Power Amplifier).	Oscilloscope is used to check trigger pulse at J-1405 on front panel of modulator MD-276 (I PA modulator). Oscilloscope set-up and adjustments required. Proper reading listed in T.O.
3.　Meter reading on Amplifier-Mixer, Intermediate Power Amplifier and Power Amplifier are observed and checked against required values. No cathode current on meter M-7702 of Amplifier-Mixer AM-1347 indicates trouble is in second amplifier stage or power supply (PP-1347).	Cathode current meter M-7702 provides front panel indication of trouble in AM-1347. Proper value listed in T.O.

TABLE 5.3 (Cont.)

Maintenance Analysis Continuation Sheet	
Equipment <u>AN/FPS-20</u> Part <u>R-7801/FPS-20</u> Task No. <u>1</u>	
Maintenance Steps	Scoring Comments
4. Power Supply PP-1377 monitors are observed (fuse lights and meters) to isolate trouble to the amplifier or power supply No 620 V.D.C. noted on meter (M-7801).	Front panel mounted meter M-7801 and fuse lights provide rapid check of A.C. input voltages to rectifiers and D.C. voltage to amplifier tubes. Proper meter reading listed in T.O.
5. Power Supply PP-1377 is removed from front of cabinet and the 620 V.D.C. circuit checked. Tube check made prior to chassis removal from cabinet. Trouble is isolated to open resistor.	External access requires removal of power supply from cabinet. Chassis must be removed partially to allow disconnecting of cables located in rear. Power Supply contains heavy transformers and filters requiring strength and endurance. Two men required to remove and place on work bench. Multimeter and tube checker required to isolate trouble resistor in 620 V.D.C. section. Spring lock fasteners permit rapid removal of chassis. Resistor board mounted on the underside of chassis by screws. Resistor is soldered to terminals. Some delay to be expected in repair action due to part location and necessity to use care in part removal to avoid heat damage or solder contamination to adjacent parts.

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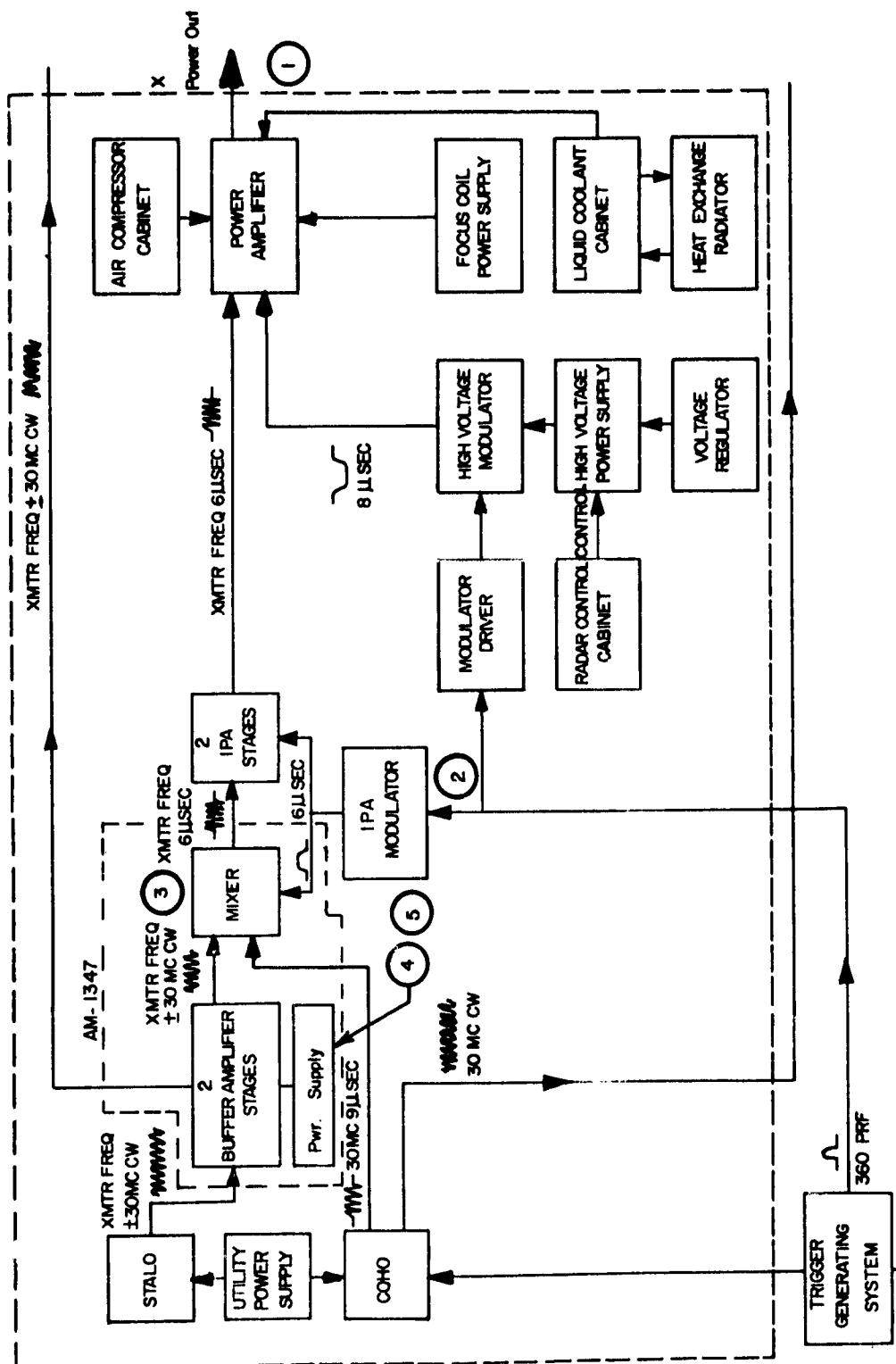
FIGURE 5.5. AN/FPS-20, TRANSMITTING SYSTEM

5.4.2.2.2 Figure 5.6, "Amplifier Mixer AM-1347/FPS-20,"
illustrates the mechanical layout of the section of the
equipment within which the defective part was located.
As indicated in the maintainability analysis, the plate
power supply sub-chassis had to be removed for further
testing. Figure 5.7, "Expanded View, Plate Power Supply,"
shows the underside of the power supply. Here, the
terminal board on which resistor R-7801 is located has
been identified. Functionally, the use of resistor
R-7801 is illustrated in Figure 5.8, "Plate Supply Block
Diagram." The resistor provides continuity between the
rectifier and series dropping electron tubes. Its opening
caused loss of plate supply voltage to the buffer amplifier,
thus preventing operation of the transmitter.

5.4.2.2.3 These illustrations, in association with other
technical material secured from the applicable technical
order, provided the basis for the scoring comments in the
Maintenance Analysis Continuation Sheet (Table 5.3).

5.4.3 Task Scoring - The design prediction is accomplished
by completing the three design related checklists for
sample tasks. Specifically, these checklists are: A,
Scoring Physical Design Factors; B, Scoring Design
Dictates-Facilities; and C, Scoring Design Dictates-
Maintenance Skills. These checklists are presented in
Appendix I of this report, together with all instructions
necessary for scoring each item.

5.4.3.1 The scoring for each item ranges from 0 to 4.
Intermediate values of 1, 2, and 3 are provided for some
questions where the nature of the characteristic being
assessed may take on varying magnitudes. This is con-
trasted to the yes-no situation. The questions have
been framed in a manner that permits general application
across equipment lines.

5.4.3.2 Situations may arise where insufficient informa-
tion is available to score a particular checklist question;
or, a question is not applicable to a particular task.
If insufficient data is available, the average question
score for the checklist should be inserted. For example,
if 14 questions were scored and the total score was 42,
the average question score is three. Inserting this value
for the unevaluated item, the final score is 45. For
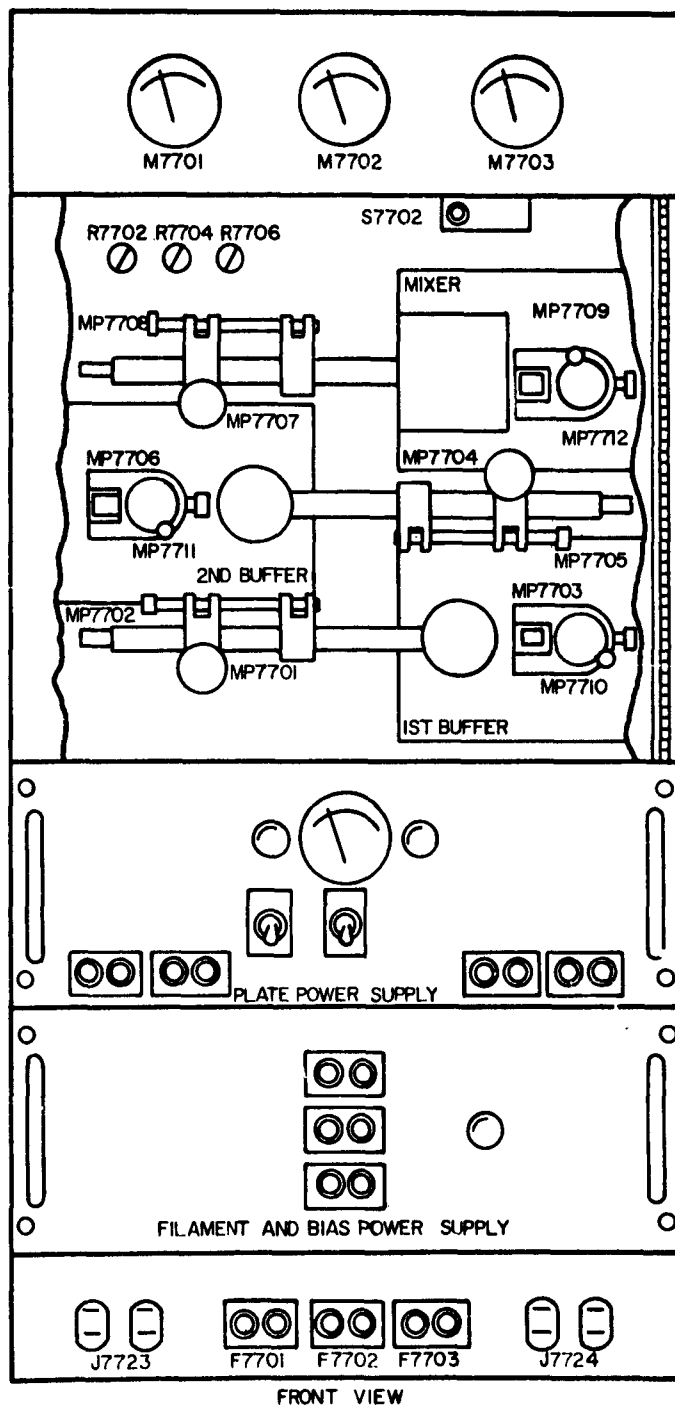
FIGURE 5.6. AMPLIFIER-MIXER, AM-1347/FPS-20

R-7801

Board 115

Board 118

FIGURE 5.7. EXPANDED VIEW, PLATE POWER SUPPLY

110
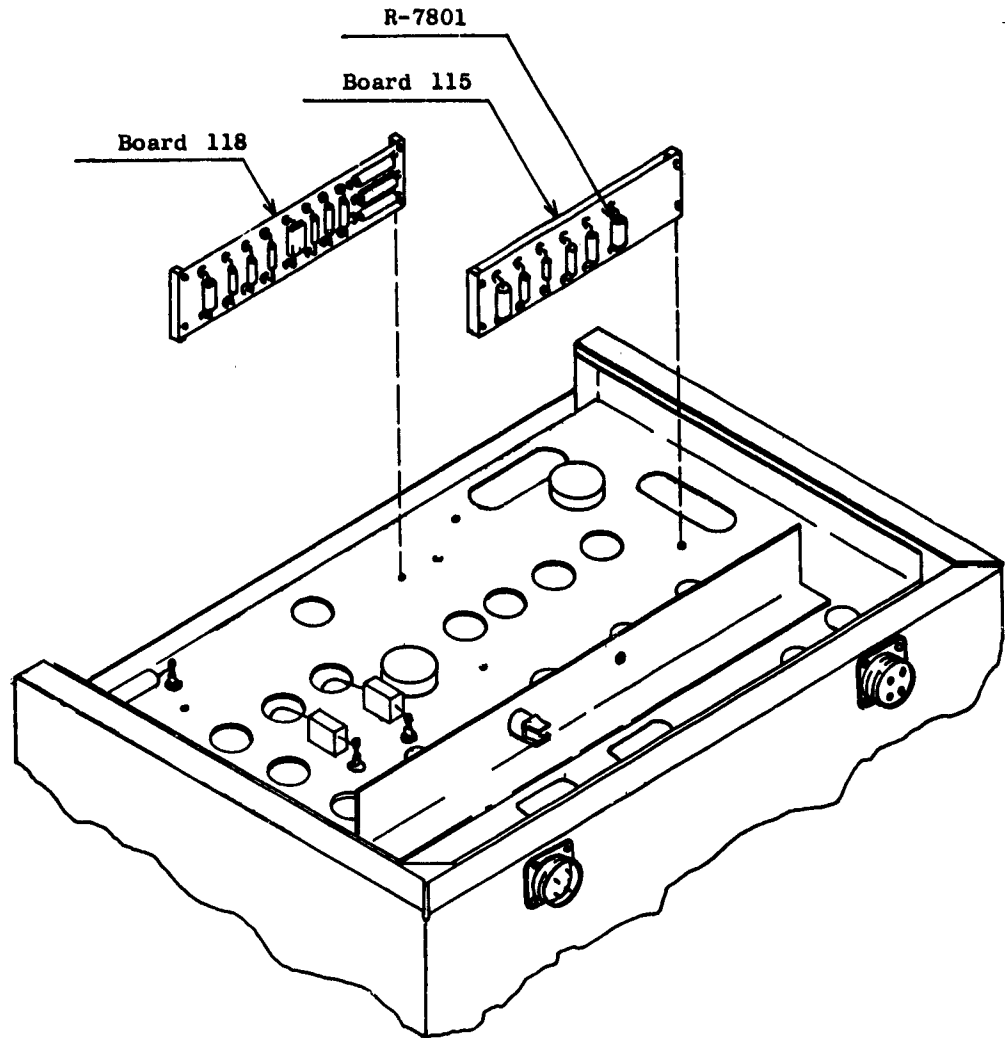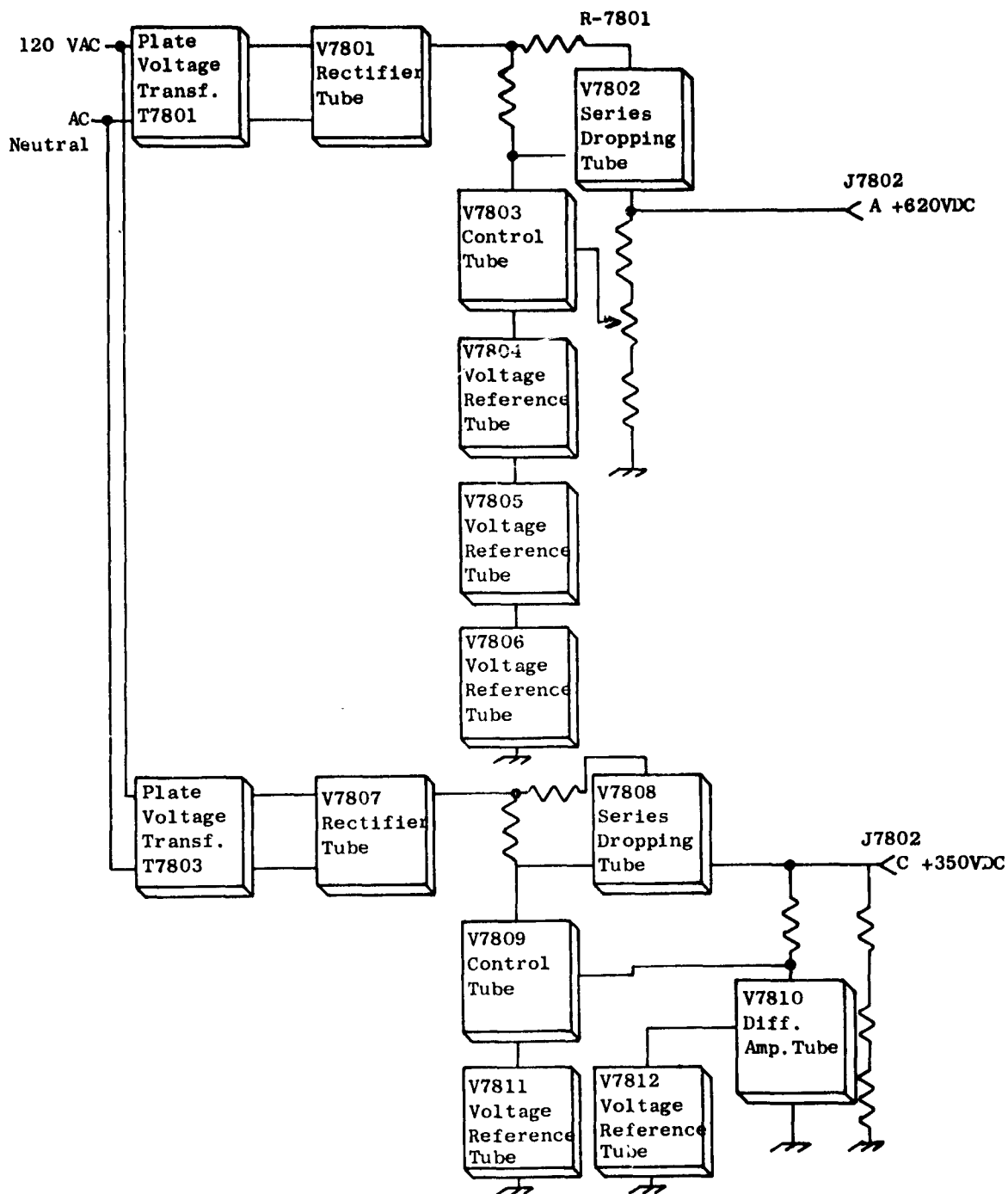
FIGURE 5.8. PLATE SUPPLY, BLOCK DIAGRAM

the other situation, i.e. not applicable, a score of 4 should be used. The reasoning here is that if a particular item does not apply, it is not detrimental to maintenance.

5.4.3.3 To illustrate the scoring process, the scores obtained for the sample maintenance analysis task are shown in Table 5.4, "Task Prediction, R-7801." The score for each checklist question is obtained by referring to the scoring comments in the maintenance analysis and the technical data available for the equipment. The task was reviewed for items that pertain to each question and the questions were then scored in accordance with the criteria, presented in Appendix I. In cases where the quality of a feature is scored, the worst condition encountered is used.

5.4.3.4 To illustrate further how checklist scores are obtained some of the specific scores in Table 5.4 will be examined. In checklist A, question two received a score of two (external latches and fasteners meet two of the criteria that they are captive, need no special tools, and require only a fraction of a turn for release.) Examination of Figure 5.6 reveals that the drawers are fastened by four multiturn screws, and the equipment T.O. indicates that these screws are captive. Since these screws can be removed using a common screw driver, the only criteria for question A not met is that they require more than a fraction of a turn to release. In checklist B, question one received a score of one (2 or 3 pieces of test equipment are needed). Examination of Table 5.3 indicates that an oscilloscope, multimeter, and tube checker were used to accomplish this task. For checklist C, question five received a score of one (above average requirement for logical analysis). This score was assigned because the initial symptoms gave very little indication as to the cause of malfunction and because a number of the major units had to be checked to isolate the trouble to a functional area.

5.4.4 <u>Downtime Calculation</u> - The last step in the prediction process is to calculate the predicted down time for each task. This is accomplished by inserting the total checklist scores for each task in the following equation:

$$M_{ct} = \text{Antilog } (3.54651 - 0.02512A - 0.03055B - 0.01093C)$$
$$(5.1)$$

TABLE 5.4

TASK PREDICTION, R-7801

MAINTAINABILITY PREDICTION FORM

Equip. __AN/FPS-20__   Unit/Part __R-7801__   Task No. _____

Ass'y. _____   By _____   Date _____

Primary function failed unit/part __Series resistor in 620__
V. D. C. power supply output network. _____

Mode of failure __Resistor opened_____

Malfunction sumptoms __No return on radar indicator_____

Maintenance Analysis

Maintenance Steps	Scoring Comments
See Table 5.3	

Checklist Scores

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
A	4	2	4	2	0	2	2	2	3	2	4	4	4	2	4	41
B	1	4	4	4	4	2	4									23
C	1	3	3	2	1	2	2	2	2	2						20

Predicted down time. . . . . __40__ Min.

The derivation of this equation is given in a previous report "Maintainability Prediction Technique." [4] To facilitate this calculation a nomograph was developed for the prediction equation and is shown in Figure 5.9, "Nomograph-Downtime." The use of this nomograph permits the determination of down times directly in real time (instead of log values.) All instructions for use of the nomograph are contained in Figure 5.9.

5.5 Calculation of Maintenance Indices

The task down times computed from the task scores provide the data for calculating various maintenance indices. The indices usually specified for ground electronics are the mean active down time and the maximum active down time (95th percentile.) These indices can be calculated from the predicted data using the procedures outlined in Section 2. Other indices described in this section may also be computed.

5.6 Levels of Application

The application of the prediction technique possesses some degree of flexibility. For example, the scoring criteria are equally applicable for several methods of replacement; i.e., part, module, or subassembly. The prediction technique thus is not limited in application by a particular type of maintenance concept. The evaluator must clearly state the working parameters and follow them faithfully to assure the greatest accuracy in the prediction.
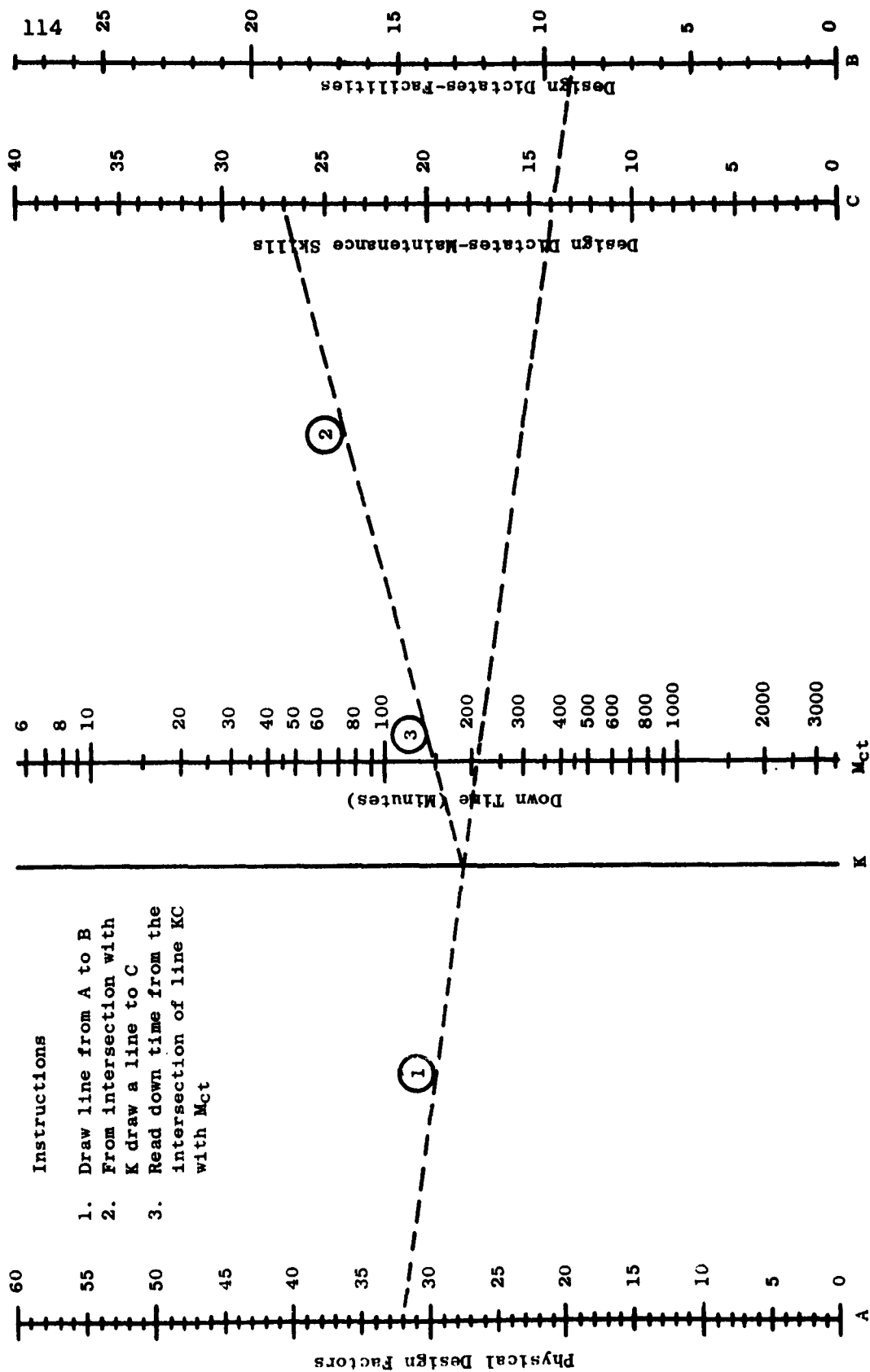
FIGURE 5.9. NOMOGRAPH - DOWN TIME

6. DESIGN REVIEW

6.1 Requirements

The design review process was originally established for achieving reliability objectives. This technique has since been expanded to include all major attributes of system design. It follows then, that design review should be used as a tool for maintainability control and improvement. The factors which affect equipment maintainability are readily amenable to this technique. Maintainability specifications require that a formal design review program be established for each development and that the reviews be documented.

6.1.1 Philosophy - The basic idea of design review is the impartial analysis of a design by experts in the various technologies that are important to the success of that design. The comments generated by the reviewers are documented and the original designer must incorporate recommended changes or substantiate the original configuration. This procedure allows the designer to gain the benefit of the experience of personnel working in specialized areas. Design review meetings should be held at each stage during a development to assure that changes may be easily incorporated and to maintain control over the approved design. These reviews should be made at each level from the basic assembly to the total system.

6.1.2 Tasks - The design review procedure entails four major tasks. These are: assemble data, actual review, documentation, and follow-up. The information required for the maintainability area is as follows:

a. Electrical and mechanical drawings;

b. Mock-ups, breadboards, or prototypes;

c. Maintainability prediction data;

d. Maintainability test data; and

e. Description of the maintenance concept.

The actual review should be performed by personnel familiar with maintainability theory, maintenance processes, and human factors. All comments generated by the reviewers are reported in the minutes of the design review meeting which are forwarded to the responsible designer. The designer must then show compliance with the design review findings or substantiate instances of non-compliance.

6.2 Analysis Methods

The personnel performing a maintainability design review need tools with which to evaluate a design. These tools or analysis methods fall into two categories: quantitative and qualitative. The quantitative techniques make use of the prediction data to determine areas and features requiring improvement. The qualitative techniques make use of the knowledge and experience of the reviewer augmented by reference material. Examples of each method are given in the following paragraphs.

6.2.1 Use of Prediction Data - The maintainability prediction technique provides three types of data useful in analyzing equipment design. These data are: maintenance task active down times, design checklist scores, and maintenance analysis comments. These data may be used to reduce both the mean and/or the maximum equipment down time. Since any reduction in the mean will cause a simultaneous reduction in M_{max}; methods for reducing the equipment mean down time are presented in the following paragraphs.

6.2.1.1 Active Down Time Analysis - There are two methods that use down time data to determine equipment areas that need improvement. The first method is the tabulation of the predicted down times in decreasing order. The first task on the list, together with all similar tasks in the equipment, is improved. This is accomplished through the use of the maintenance analysis comments for that task, and the design guidelines (see Section 4) that apply to the checklist questions which received low scores for that task. This procedure is repeated for each succeeding task on the list. The number of tasks selected for improvement in this manner is dependent upon the time and resources available.

6.2.1.1.1 The other method is, occasionally, one or more of the major units have significantly higher mean down times than the total equipment. In this case, improvement of these units could be the most economical method for reducing the mean down time. The first step in applying this method is to determine the mean down time for each major unit from the predicted down times. The units with the highest means can then be improved through the use of the method given in paragraph 6.2.1.1. The methods given in the following paragraphs may also be used to improve the selected units.

6.2.1.2 <u>Analysis of Design Checklist Scores</u> - The design scores obtained from the prediction can be used to determine the design features which most adversely affect the equipment down time. The first step in this procedure is to determine the average score for each checklist question. The questions having an average score of less than three for checklists A and B, and less than two for checklist C, are then determined. These questions are then grouped in accordance with the ordered list of design features given in paragraph 4.2.1.1. The selected items are improved through the use of the design guidelines applicable to each selected question and through the use of maintainability design handbooks [122]. If questions in the lower groups have extremely low average scores, they should be given special consideration.

6.2.1.3 <u>Use of Maintenance Analysis Comments</u> - In completing the maintenance analysis comments for each prediction task, features which inhibit the maintenance action are noted. In some cases the lack of desirable features are also noted. To use this information to improve equipment maintainability, the feature described above are first grouped according to the checklist question affected. These features can then be improved by means suggested through consideration of the design guidelines and maintainability handbooks. If insufficient resources are available to improve all affected features, selection may be made on the basis of the ordered list of design features.

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6.2.1.4 Method Selection - The first problem in the use of
the prediction data for equipment/system maintainability
improvement is the selection of the best method for a partic-
ular situation. In most cases a thorough review of the
prediction data will point out the most promising method.
If the best method is not obvious, sample analyses can be
made and the results of each compared. In many cases the
individual evaluator will have a personal preference for a
particular method. If the maximum downtime exceeds the
specification and the mean does not, the methods described
in paragraph 6.2.1.1 or 6.2.1.1.1 become preferable.

6.2.2 Qualitative Assessment - If data are not available to
perform a quantitative analysis of an equipment, qualita-
tive techniques may be used. These techniques may also be
used to augment the quantitative analysis. The qualitative
analysis is performed by the personnel on the design review
board, who are responsible for the maintainability aspect
of the equipment under review.

6.2.2.1 The personnel performing the maintainability de-
sign review should possess a thorough understanding of
theory of maintenance. They should also be familiar with
maintenance procedures, statistics, and human factors con-
siderations. The reviewers should check the design for any
obvious features detrimental to maintainability. They
should determine if the requirements of the system main-
tenance concept are met. The reviewers should also deter-
mine if there are any interface problems with associated
prime equipment or with the programmed support equipment.
Past experience with similar equipment, and information
derived from maintainability and human factors handbooks
should be drawn upon to determine what changes are neces-
sary to improve the equipment maintainability.

6.2.2.2 To assist the maintainability design reviewers,
a checklist for maintainability features should be pre-
pared. This checklist would encompass the major factors
important to maintainability as well as individual features
deemed important to the class of equipment under review.
This checklist could also be used to assist personnel, not
intimate with maintainability, to perform the design review
when experienced personnel are not available. An example
of a general checklist for maintainability design review
is shown in Table 6.1, "Sample Maintainability Checklist."

TABLE 6.1 SAMPLE MAINTAINABILITY CHECKLIST

A. MAINTENANCE CONSIDERATIONS FOR ELECTRICAL DESIGNERS

1. Are the maintenance and test equipment requirements compatible with the concept established for the system?

2. Does the unit require special handling?

3. Can the unit be readily installed and connected to the system?

4. Are factory adjustments such that they do not require readjustment when units are replaced in a system or when parts are replaced in the unit in the field?

5. What adjustments are necessary after a unit has been installed in the system?

6. Are adjustments capable of compensating for all possible tolerance buildups?

7. Is periodic alignment and/or adjustment recommended? How often?

8. Are all requirements for maintenance tests such that the specified time limitations can be met?

9. Has the number of factory adjustments been minimized?

10. Has the number of field adjustments been minimized?

11. Are interconnected circuits in the same package, thus providing minimal inputs and outputs at each maintenance level?

12. Is the interaction between adjustments and other cir-
cuit parameters minimized?

13. Is the design such that damage to the circuit cannot
result from careless use of an adjustment or combination
of adjustments?

14. Are all adjustments and indicators of the "center-zero"
type where possible?

15. Is periodic testing necessary? How often?

16. Are the test points adequate? Are they accessible in
the installed condition?

17. What overhaul testing is required?

18. What specific test equipment is necessary?

19. Have factory and maintenance test equipment require-
ments been minimized and coordinated with the require-
ments for other units?

20. What special techniques are required in the repair,
replacement, or alignment of the unit?

21. Are parts, assemblies, and components placed so there
is sufficient space to use test probes, soldering iron,
and other tools without difficulty? Are they placed
so that structural members of units do not prevent
access to them?

22. Are testing, alignment, and repair procedures such that
a minimum of knowledge is required on the part of main-
tenance personnel? Can trouble shooting of an assembly
take place without removing it from a major component?

23. What special tools and/or test equipment are required?

24. Can every fault (degrading or catastrophic) which can possibly occur in the unit be detected by the use of the proposed test equipment and standard test procedures?

25. Have parts subject to early wear-out been identified? Have suitable preventive maintenance schedules been established to control these parts?

26. Are the components having the highest failure rates readily accessible for replacement?

27. Are parts mounted directly on the mounting structure rather than being stacked one on another?

28. Are units and assemblies mounted so that replacement of one does not require removal of others?

29. Are limiting resistors used in test-point circuitry; i.e., is any component likely to fail if a test point is grounded?

30. Can panel lights be easily replaced? (Panel lights should not be wired in series).

31. Have voltage dividers been provided for test points for circuits carrying more than 300 volts?

32. Will the circuit tolerate the use of a jumper cable during maintenance?

33. Are controls located where they can be seen and operated without disassembly or removal of any part of the installation?

34. Are related displays and controls on the same face of the equipment?

35. Are all units (and parts, if possible) labeled with full identifying data? Are parts stamped with relevant electrical characteristics information?

36. Are cables long enough to permit each functioning unit to be checked in a convenient place?

37. Are plugs and receptacles used for connecting cables to equipment units, rather than "pigtailing" to terminal blocks?

38. Are field-replaceable modules, parts, and subassemblies, plug-in rather than soldered?

39. Are cable harnesses designed for fabrication as a unit in a shop?

40. Are cables routed to preclude pinching by doors, covers, etc.?

41. Is each pin on each plug identified?

42. Are plugs designed to preclude insertion in the wrong receptacle? Are plug-in boards keyed to prevent improper insertion?

43. Has consideration been given towards isolating trouble areas without complete equipment shut down?

B. **MAINTENANCE CONSIDERATIONS FOR MECHANICAL DESIGNER**

1. Are all items (parts and subassemblies) visually and physically accessible for assembly, wiring rework, and maintenance?

2. Are all test points accessible when the unit is properly installed?

3. Are all field adjustments accessible when the unit is properly installed?

4. Has sequential assembly been avoided which results in involved sequential disassembly in order to make repairs and adjustments?

5. Is the design such that no unrealistic requirements for special facilities for maintenance, storage, or shipment are imposed?

6. Is the design such that no unnecessary requirements for a special maintenance environment (e.g., ground power carts, cooling, special primary power, etc.) are imposed?

7. Does the design provide for adequate protection of maintenance and test personnel against accidental injury?

8. Is each assembly self-supporting in the desirable position or positions for easy maintenance?

9. Can assemblies be laid on a bench in any position without damaging components?

C. HUMAN ENGINEERING CONSIDERATIONS FOR OPERATION AND MAINTENANCE

1. Are visual indicators mounted so that operator can see scales, indices, pointers, or numbers clearly?

Are scale graduations, design of numerals and
pointers, and scale progressions presented so that
accurate reading is enhanced?

2. Do visual displays have adequate means for identify-
   ing an operative condition?

3. Have ambiguous information and complicated inter-
   polations been eliminated from visual indicators
   to minimize reading errors?

4. Do controls work according to the expectation of
   the operator?

5. Do functionally related controls and displays main-
   tain functional or physical compatibility, such as
   direction-of-motion relationships or proximity to
   each other?

6. Are controls designed so that the operator can get
   an adequate grip for turning, twisting, or pushing?

7. Does console design provide knee room, optimum
   writing surface, height, or optimum positions for
   controls and displays?

8. Do equipment design and arrangement allow space for
   several operators to work without interfering with
   each other?

9. Do arrangement and layouts stress the importance
   of balancing the workload, or do they force one
   hand to perform too many tasks while the other
   hand is idle?

10. Is the illumination designed with the specific task
    in mind, rather than with a general situation?
    (Many instruments are practically useless because
    of lack of illumination.)

11. Have extreme glare hazards been eliminated, such
    as: brightly polished bezels, glossy enamel finishes,
    or highly reflective instrument covers?

12. Are assemblies and parts stacked so that some have
    to be removed to repair or replace others, thus
    complicating maintenance?

13. Do fasteners for chassis and panels require special
    tools?

14. Do chassis door slides have means for holding the
    unit extended for servicing? Are the slides too
    loose, or do they bind?

15. Are handles provided, and are the chassis or units
    light enough to be moved without undue strain?

16. Is calibration indexing provided for maintenance
    adjustment and calibration adjustment controls?
    (screwdriver adjustments are often too sensitive.)

17. Do the coding and symbols on equipments and in
    instruction manuals coincide?

18. Is sufficient illumination provided for the
    maintenance technician to read T.O.'s, etc.?

6.3 <u>Trade-Off Techniques</u> - To meet overall system require-
ments within a budgeted cost, it is often necessary to per-
form trade-offs among the major system parameters. Such
trade-offs within the major parameters are also necessary
to attain the specified levels for each parameter. In the
case of maintainability, a trade-off may be effected with
reliability to achieve the desired availability. At the
same time, however, mission requirements may dictate a
minimum maintainability requirement, below which a trade-
off may not be made. In this situation, trade-offs among
the parameters of maintainability (design, personnel, and
support), or among the components of the system, may be
necessary to achieve the required maintainability level.
The following paragraphs give techniques for performing
these trade-offs.

6.3.1 <u>System Availability Trade-Off</u> - Availability is
defined as the probability that a system/equipment is
operating satisfactorily at any point in time when used
under stated conditions. Availability is dependent on
reliability and maintainability through the following
relationship:

$$A_i = \frac{MTBF}{MTBF + \bar{M}_{ct}} \tag{6.1}$$

Where:

A_i = inherent availability

$MTBF$ = mean time between failure

$\bar{M}_{ct}$ = mean corrective down time

Since availability reflects two fundamental measures of
system dependability, its use in analytically evaluating
a system appears advantageous.

6.3.1.1 To illustrate the use of availability for trade-
offs, Figure 6.1, "Weapon System A," was developed. Weapon
system A is depicted as containing five subsystems for which
the reliability and maintainability have been predicted.
Table 6.2, "Weapon System Availability," summarizes the
mean time between failure and the mean down time, showing
the availability for each subsystem.
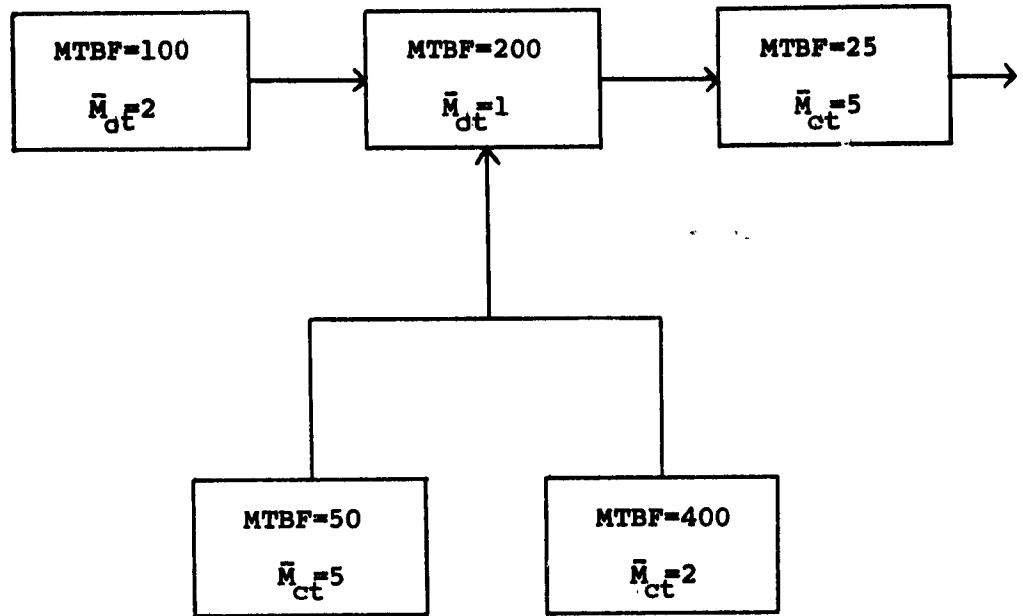
FIGURE 6.1.   WEAPON SYSTEM A

TABLE 6.2

WEAPON SYSTEM AVAILABILITY

Subsystem	MTBF	$\bar{M}_{ct}$	A_i
1	100	2	.98039
2	200	1	.99502
3	25	5	.83333
4	50	5	.90909
5	400	2	.99502

The system availability is calculated by forming the product of the individual availibilities, assuming independance of A_i.

$$A_s = A_1 \times A_2 \times A_3 \times A_4 \times A_5 \qquad (6.2)$$

Using this formula the availability for weapon system A is:

$$A_s = (.98039) \ (.99502) \ (.83333) \ (.90909) \ (.99502)$$
$$= 0.73534$$

6.3.1.1 If the maintainability of an equipment has been improved to the state-of-the-art or the budgetary limitations and still does not meet the specified level, a trade-off may be made with reliability to attain the desired availability. To illustrate this procedure weapon system A as described above will be used. Examination of table 6.2 shows that subsystem 3 has the lowest availability. Thus, it is reasonable to conclude that providing an alternate subsystem (redundant) will improve the total system availability. The availability for the redundant subsystem 3 can be calculated as follows:

$$A_{3r} = 1 - (1-A_3)^2 \qquad (6.3)$$

Where:

A_{3r} = subsystem redundant availability

substituting the value for A_3 gives:

$$A_{3r} = 1-(1-.83333)^2 = .97222$$

Substituting the value for A_{3r} in the system availability equation gives:

$$A_s = (.98039)(.99502)(.97222)(.90909)(.99503) = 0.85790$$

The introduction of redundancy for subsystem 3 has resulted in an increase of total system availability. This increase, however, was achieved with the added penalties of cost and complexity.

6.3.1.2 An alternate method for increasing availability is to increase the maintainability of the system through a trade-off between the design and support parameters. The basic method for performing this trade-off is to change the maintenance concept so that more of the burden is placed on the support parameter. As an illustration, assume that a sophisticated maintenance checkout equipment is developed for weapon system A. This equipment reduces the maintainability requirements for the weapon system by one-half. Table 6.3, "Weapon System A Availability (With Support Equipment)," illustrates the availability achieved through the use of the checkout equipment.

TABLE 6.3

WEAPON SYSTEM A AVAILABILITY
(With Support Equipment)

Subsystem	MTBF	$\bar{M}_{ct}$	A
1	100	1.0	.99009
2	200	.5	.99751
3	25	2.5	.90909
4	50	2.5	.95238
5	400	1.0	.99751

The weapon system availability achieved through this method is calculated as follows:

$$A_s = (.99009)(.99751)(.90909)(.95238)(.99751)$$

$$= 0.85296$$

Again a substantial gain has been achieved but at a greater cost for the system. An additional degradation factor presented by use of the support equipment is its potential unavailability. This factor may be analytically treated to incorporate this degradation into the weapon system availability.

6.3.1.3 To select the best method for improving availability, the relative cost for each approach must be estimated for the examples given, it is assumed that each configuration possesses the same performance capability, and that the development costs are as shown in Table 6.4, "Weapon System Parameters."

TABLE 6.4

WEAPON SYSTEM PARAMETERS

	Configuration	Development Cost (Dollars)	Availability
I.	Basic System	$500,000.00	.73534
II.	Redundant System	550,000.00	.85790
III.	Basic System Plus Support Equipment	560,000.00	.85296

The data in Table 6.4 shows that configuration II has the highest availability with the least increase in development cost.

6.3.1.4 In summary, tabulation of system data as described in the above example, permits detailed examination of alternate system configurations. Evaluation of the individual parameters against operational and other constraints, permits the optimum configuration to be selected. In the example only two alternate configurations were considered. Actual use of this analytical approach for system optimization would entail examination of a broad range of alternates.

(A trade-off between the design and personnel parameter
might be effected by specifying a higher skill level for
the maintenance personnel.) It should be noted that the
example is based on development costs and that the effect
on support cost by the proposed changes is not shown.
Where procurement is based on the cost for the life of a
system; the total cost should be calculated for each al-
ternate configuration and the selection be made on a least
total cost basis.

6.3.2 <u>Component Availability Trade-Off</u> - The technique
described for trading off maintainability against re-
liability at the system level is also applicable at the
sub-system, equipment, and component level. Basically,
at the component level, the costs of increasing reliability
and maintainability through redesign are calculated for
various levels of each attribute. The availability for
each combination of reliability and maintainability
levels is calculated along with the associated develop-
ment cost. This data is then tabulated as in Table 6.4
and the method for improvement is selected on the basis
of mission requirements and budgetary limits.

6.3.3 <u>Component Apportionment Trade-Off</u> - The maintain-
ability of a system/equipment may be improved by re-
apportioning the component requirements. To illustrate
this process, equipment D which was shown in Figure 4.1,
will be used. In this equipment, components A and B
contribute to maintenance in accordance with their
respective failure rates while component C contribute
to all maintenance tasks. It would follow then that an
improvement in component C would result in a greater im-
provement in equipment maintainability than a correspond-
ing improvement in either component A or B. In more
complex equipment it is possible that alternate con-
figurations of the basic components will permit a more
economical improvement in equipment/system maintainability.

7. DEMONSTRATION TESTING

7.1 General Approach

Maintainability specifications call for the demonstration of achieved mean and maximum down time for electronic systems.[5] This section outlines a testing procedure designed to fulfill these requirement . The testing procedure entails the introduction of failed parts or modules into the system to establish a requirement for maintenance. Trained technicians are used to accomplish maintenance routines to locate and repair the malfunction. Monitoring of these routines permits time data and other useful information to be derived. Discussions include the test planning phase, the administration of the test program, and the data analysis process necessary to derive the mean and maximum down time measures.

7.2 Test Planning Phase

The planning for demonstration testing is most important. It includes selecting personnel, establishing the test environment, selecting tasks, and developing data handling methods. Each of these areas will be discussed in some detail.

7.2.1 Personnel - Directly involved in the testing program are the maintenance technicians and the test monitors. The maintenance technicians performing the selected tasks require specific training on the equipment under test plus normal electronic training and experience. Specific equipment training required is a function of complexity of the equipment under test. Typically, it may be expected that an experienced technician would require two weeks equipment training. As a point of comparison, training for typical Air Force technicians was found to be comprised of 36 weeks of which 15 were devoted to specialized training in electronic theory, and 21 to equipment operation and maintenance procedures. [3] Additionally, these technicians had a high school education and approximately one and one-half years of general maintenance experience. This information may be found useful in guiding technician selection.

7.2.1.1 The number of technicians to be employed in the testing is somewhat flexible. Obviously, the greater number employed, the better chance for the resultant data to reflect average technician capability. A typical program may employ five technicians performing ten tasks each.

7.2.1.2 In addition to the technicians, it is necessary to provide monitors to observe and record the actions resulting from maintenance task performance and their associated times. Personnel to fulfill this function preferably should have a maintenance engineering background. Additionally, they should be trained in time study techniques and be thoroughly familiar with the specific data collection requirements. It is extremely important that the monitors selected are capable of carrying out the program as intended.

7.2.2 Test Environment - Although the equipment and the maintenance personnel are key factors in determining maintenance down time, the environment in which maintenance is performed also contributes. It is, therefore, necessary that attention be directed toward establishing a test environment which simulates as closely as possible the expected operational use conditions. Specifically, attention must be given to the following details:

    a. Physical layout of the equipment
    b. Work space and lighting
    c. Work benches and related facilities
    d. Tools - standard and/or special
    e. Test equipment
    f. Technical data
    g. Spare parts

Definitive statements should be developed outlining the manner in which each of the above areas will be handled in the test situation. Such details must be established to assure that a controlled test is achieved.

7.2.3 Task Selection - Maintenance may be performed at one of several levels; i.e., organizational field, and depot. Since different task types may exist at these levels, it is important to specify the test level and chose consistent tasks.

7.2.3.1 Maintainability specifications provide a procedure for selecting specific tasks to be used in the demonstration testing. Basically, it involves the random selection of tasks from part or module groups which have been stratified in accordance with the product of their

failure rate, population, and expected maintenance con-
tribution. A minimum of fifty tasks are usually required.
The procedure set forth has been found to be straight-
forward except for the area of determining expected main-
tenance time for part or module classes. Experience has
indicated that development of such maintenance time stan-
dards appears doubtful. For example, maintenance time
for tasks involving a defective vacuum tube will vary widely
depending upon its use and the physical features of the
equipment in which it is employed. Consequently, it is
felt that the group maintenance time contribution must be
approached from an equipment application standpoint rather
than group averages. The maintainability prediction tech-
nique described in Section 5 should provide a means of
evaluating the equipment application time requirements.

7.2.3.2 To illustrate the task selection procedure for
corrective maintenance Table 7.1, "Task Selection Distri-
bution," has been prepared. Here, the part types used
in the equipment have been identified and the quantity
used noted. Reliability data provides the average part
failure rates. The product of the quantity and the failure
rate yields the expected number of failures per thousand
hours. In this example, it was found by totaling the part
failures that 6.391 failures to the equipment could be ex-
pected per thousand hours. This figure was then used as
a base for determining the percent contribution to total
failures for each part class. For example, the tube class
contributes 73.8% from the relation 4.717/6.391 x 100.

7.2.3.2.1 Finally, the percentage contribution of each part
class is used to apportion the fifty task sample. To
illustrate this operation, 37 tube failures will be included
in the sample because 50 x .738 yields 36.9 or 37. For the
example provided, differences in maintenance contribution
were not considered since the equipment under test possessed
a homogeneous design. However, should the test designer
be faced with evaluating an equipment utilizing different
design concepts, the inclusion of a maintenance contri-
bution apportioning factor must be made.

7.2.3.3 With knowledge of the number of part types to be
simulated, a random selection process will identify specific
parts to be used. For this purpose a table of random
numbers or similar devices may be used to designate the
maintenance tasks.

TABLE 7.1

TASK SELECTION DISTRIBUTION

Part Class	Quantity	Average Part Failures %/1000 Hrs.	No. of Expected Fail./1000 Hrs. Operation	Contrib. to Total Expected Failures (%)	No.of Fail. for Sample of 50	Actual Failures
Blowers/Motors	44	.189	.083	1.30	.65	1
Capacitors	505	.010	.051	.80	.40	0
N-type Diodes	19	2.983	.567	8.87	4.44	4
Connectors	261	.032	.084	1.31	.66	1
Relays	74	.359	.266	4.16	2.08	2
Coils	71	.033	.023	.35	.18	0
Resistors	1517	.015	.228	3.57	1.79	2
Switch	176	.045	.079	1.24	.62	1
Transformers	85	.133	.113	1.77	.89	1
Tubes	301	1.567	4.717	73.81	36.91	37
Misc.	101	.178	.180	2.82	1.41	1
Total	3154		6.3910	100.00		50

7.2.3.4 The task selection procedure discussed above applies directly to corrective maintenance tasks. Maintainability specifications further call for the identification of preventive maintenance tasks and the accomplishment of a representative sample of those tasks which will involve operational down time. The testing procedure discussed herein will be equally applicable to this area.

7.2.4 <u>Data</u> - The prime purpose of the testing program is to determine the down time requirements for a sample of representative tasks. The specification states that down time includes recognition, diagnosis, repair, and checkout. Although only total down time is required, much can be learned by recording the maintenance time elements. For example, an examination of a detailed maintenance record may reveal that excessive time is spent in assembly or disassembly actions. Such knowledge will provide a means to initiate corrective action.

7.2.4.1 To record maintenance time data, it has been found that use of a running clock and recording a brief description of each action and its time of occurrence is the best method. Upon completion of the task, these individual actions may be classified into more general groupings. Figure 7.1, "Maintenance Worksheet," illustrates the method. Figure 7.2, "Task Time Summary Sheet," shows a format for consolidating the individual task actions. This basic time data may be further supplemented by information relating to such areas as human factors, operational procedures, etc.

7.3 Administration Procedure

To carry out the test procedure, it is necessary that the administration procedures to be clearly defined. Program implementation, organization and scheduling form the primary considerations. These areas are discussed in the following paragraphs

7.3.1 <u>Program Implementation</u> - Prior to the actual testing it is necessary that the equipment, to be evaluated, be operational. The tasks selected for the program should be pretested in the equipment to determine their effect. Obviously, tasks involving defective parts, which may result in damage to the equipment, should be controlled. It is additionally important that the insertion of a

Task No. 1		Technician J. Jones
Equipment AN/XYZ	Date 7-11-62	Monitor W. Smith

Time (minutes)	Action
00.0	Start .
01.5	Checked output meter
03.5	Removed dust cover
07.2	Secured and Adjusted scope
10.8	Took scope reading
12.5	Replaced tube (V101)
14.0	Checked output meter
16.2	Took scope reading
17.8	Made adjustment
19.2	Check output meter
21.5	Replaced cover
23.0	Checked meter
	Task Complete
	Note: Dust cover secured by non-captive screws. Consider redesign to eliminate potential field problem.

FIGURE 7.1. MAINTENANCE WORKSHEET

EQUIPMENT	DATE	TECHNICIAN	MONITOR
AN/XYZ	7-11-62	J. Jones	W. Smith

TASK NO.	COMMENTS	ASSEMBLY AND DISASSEMBLY	INSPECTION TESTING MEASURING	REMOVE AND REPLACEMENT	CHECK-OUT	CLEANING AND LUBRICATION	SECURING MATERIALS	Total
		1	2	3	4	5	6	Total
1	V101 Replaced	4.3	10.2	3.3	1.5	0	3.7	23.0
	TOTAL							

FIGURE 7.2. TASK TIME SUMMARY SHEET

defective part or module will result in a distinct indi-
cation that one or more of the equipment operating charac-
teristics does not meet specified values. Further, it is
important that repeated use of a task will result in the
same malfunction symptoms occurring. By subjecting the
selected tasks to this pretesting, these points may be
readily determined.

7.3.1.1 To accomplish the series of selected tasks in a
controlled manner, it is important that satisfactory or
minimum performance standards for the equipment be clearly
established. If practical, prior to the insertion of each
task, monitoring personnel should determine that the equip-
ment is functioning properly. This will preclude the
possibility of securing excessive maintenance times which
would result if a defect were present other than the one
intentionally placed in the equipment.

7.3.1.2 Finally, it is necessary that a detailed routine
for accomplishing the actual testing be established. Areas
such as placement of test equipment, amount of information
to be given the technician, and other details related to the
accomplishment of the maintenance tasks must be covered.
Attention to such details will provide greater control,
thus enhancing the probability of securing meaningful data.

7.3.2 Organization and Scheduling - Since the adminis-
tration of the maintainability test program may involve
the coordinated effort of engineering, production, and pro-
duct assurance groups, it is important that clear lines of
responsibility be established prior to the start of actual
testing. It is impractical here to present a suggested
organizational relationship since these relationships are
highly dependent upon project size and the basic organi-
zation structure of the operating groups. It should be
stressed that a fully coordinated effort is needed to
secure accurate data in a timely manner.

7.3.2.1 Test scheduling must consider the availability of
the equipment, technical personnel, and the laboratory
facilities in relation to meeting the maintainability
milestones in the project schedule. Additionally, other
test programs such as reliability and performance testing
will be demanding the use of these facilities during the

same time period. Hence, it is important that the main-
tainability testing be scheduled well in advance to assure
the greatest compatibility.

7.3.2.2 Limited past experience has shown that three to
four maintenance tasks can be accomplished 'n a normal
8-hour day. Naturally, this will vary depending upon the
sophistication of the equipment under test and its in-
herent maintainability. Generally, it may be expected
that 13 to 17 days test time will be required to accomplish
a 50 task demonstration.

7.4 Data Analysis

Raw data derived from the test program must be screened
thoroughly prior to the computation of the maintainability
measures. This screening includes a review of the time
element classification as well as verification of mathematical
calculations. Following this review, calculation of mean
and maximum down time may be accomplished. Using equations
developed in Section 2, the following sample calculation was
performed.

7.4.1 Sample Calculation – To illustrate the derivation
of the mean and maximum down time quantities, Table 7.2,
"Maintainability Test Data," has been provided. This table
notes the part, its mode of failure, and its location in
the equipment with respect to the assembly and major unit.
In association with the identification information the ob-
served down time and its log to the base ten have been
listed.

7.4.1.1 The mean down time is given quickly by employing
the following equation:

$$M_{ct} = \frac{\sum_{i=1}^{N} M_{ct_i}}{N} = \frac{3366.6}{50} = 67.3 \text{ min.}$$

Maximum down time determination requires first calculation
the mean of the log (log M_{ct}) and the standard deviation of
the logs ($\sigma_{\log M_{ct}}$).

TABLE 7.2

MAINTAINABILITY TEST DATA

Task	Major Unit	Ass'y.	Part	Failure Mode	Down Time	Log M$_{ct}$
1	OA-270	IP-188	V-4008	Open Fil.	39.7	1.59867
2	OA-270	PP-795	V-4102	Open Fil.	46.9	1.67077
3	OA-270	PP-795	V-4104	Shorted Ele.	38.1	1.58122
4	OA-270	PP-795	V-4106	Open Fil.	62.7	1.79745
5	OA-270	PP-795	V-4110	Low Gm	26.4	1.42181
6	OA-270	PP-795	V-4111	Low GM	23.3	1.36717
7	OA-270	PP-795	R-4110	Open	83.1	1.91979
8	OA-270	PP-828	CR-4151	Open	124.6	2.09563
9	OA-270	IP-188	V-4306	Low Gm	54.6	1.73743
10	OA-270	IP-188	V-4402	Shorted Ele.	38.8	1.58882
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
40	OA-329	CN-187	CR-2102	Open	448.0	2.65124
41	OA-329	CY-1138	S-2204	Open	30.2	1.47959
42	PP-783	PP-793	V-10402	Shorted Ele.	52.7	1.72209
43	C-1048	C-1048	B-3901	Open Winding	54.8	1.73839
44	CN-93	CN-93	J-10303	Grounded Pin	92.4	1.96562
45	J-470	J-470	K-9710	Open Coil	34.3	1.53533
46	PU-292	PU-293	Z-3507	Open	92.4	1.96562
47	ID-331	ID-331	V-3701	Shorted Ele.	37.8	1.57789
48	ID-331	ID-331	V-3703	Low Gm	34.8	1.54184
49	ID-331	ID-331	V-3704	Low Emission	40.1	1.60301
50	C-1049	C-1049	V-3802	Low Gm	12.8	1.10714
Total					3366.6	86.36821

$$\overline{\log M}_{ct} = \frac{\sum\limits_{i=1}^{N} \log M_{ct_i}}{N} = \frac{86.36821}{50} = 1.72736$$

and:

$$\sigma_{\log M_{ct}} = \sqrt{\frac{\sum\limits_{i=1}^{N} (\log M_{ct_i})^2 - \left[\sum\limits_{i=1}^{N} \log M_{ct_i}\right]^2 \Big/ N}{N-1}}$$

$$= \sqrt{\frac{(152.66015) - (86.36821)^2 \Big/ 50}{49}} = 0.26614$$

Substituting these values in maximum down time equation as follows yields:

$$\text{Maximum Down Time} = \text{antilog} \left(\overline{\log M}_{ct} + 1.645\, \sigma_{\log M_{ct}}\right)$$

$$M_{max} = \text{antilog} \left[1.72736 + 1.645\,(0.26614)\right] = 147.1 \text{ min.}$$

7.4.1.2 The calculations shown were applied to corrective maintenance data. Similar procedures can be applied to preventive maintenance data to secure mean and maximum down time measures.

8. FIELD DATA ACQUISITION

8.1 General Requirements

Field data offers a great variety of maintenance information and gives an insight into factors which only become apparent when the equipment is used in its intended environment. Factors unique to field operation, i.e., maintenance scheduling, support, and environmental conditions can be investigated to isolate those areas important to maintainability design. In addition, the total effect of the field installation on the inherent equipment maintainability can be measured.

8.1.1 Field Data Usage - The maintenance data obtained from field installations can be used in three general areas: specification, design, and end use. In the specification area, these data provide the basis for determining realistic maintainability requirements. In the design area, field data provide information for improving equipment maintainability and for evaluating the level achieved. These data also provide the user with tools for maintenance planning and determining training and support equipment requirements.

8.1.2 Types of Data - There are essentially three types of data that can be gathered from field installations. These are time, environment, and cost. Time data result from measurements of equipment and personnel performance and are important to maintenance scheduling and capability determination. Data concerning the status of equipment, personnel, and support systems as well as the natural environment, are necessary to isolate the factors affecting maintainability and to provide information for design improvement. Cost data refers to the costs associated with the maintenance and support of an equipment. Cost data are important to the determination of realistic specification requirements and form the basis for performing trade-offs between maintainability and other system parameters.

8.2 Data Collection Techniques

There are various techniques for collecting maintenance data

at field installations. In general, the different types of
data require different techniques, while there may be more
than one way to acquire a specific type of data. Four data
collection techniques applicable to maintainability are
described in the following paragraphs. The types of data
that can be collected through the use of each technique
and the advantages and disadvantages of each are presented.
Since any program probably requires more than one type of
data, two or more of the techniques would be used together.

8.2.1 <u>Field Initiated Reports</u> - The least costly method
of data collections is to have the personnel performing
equipment maintenance fill out reports on maintenance
activities and forward them to the organization conducting
the field study. This technique allows a large amount of
data to be gathered economically. The main disadvantages
are the lack of accuracy obtainable through this method
and that the amount of detail is limited due to the lack
of time available to the reporting personnel. It is often
difficult for personnel involved with maintenance to make
impartial judgements and the basic problems are not always
apparent. If this technique is to be used, it is important
that the reporting personal be motivated to make complete
and accurate reports and that the data forms are very clear
and easy to complete.

8.2.2 <u>Field Survey</u> - Another method for acquiring large
amounts of data is through the interview of personnel at
operating sites. This survey may be conducted by personal
interview or through questionaires to be completed by the
site personnel. If the personal interview method is used,
the interviewers must be thoroughly trained in maintainability
theory, conduct of interviews, and data form completion.
Questionaires and data forms must be developed to obtain the
desired data, and the sites to be visited be selected to
obtain a good cross section of the total population. If
questionaires are to be sent to maintenance personnel for
their completion, instructions for form completion must be
developed to clearly describe the purpose of the question-
aire and questions be selected that are not easily
misinterpreted. This data collection technique is usually
not capable of gathering time data. Another drawback is
that the opinions of maintenance personnel may be biased
due to their closeness to the situation and inability to
grasp the total problem.

8.2.3 <u>Time Study</u> - There are two methods for making maintenance time measurements, one is by actual timing of maintenance actions by an observer and the other is by making random observations. The first or continuous monitoring technique is used to measure down time or technician time for specific maintenance actions. The second or work sampling technique is useful for gathering information about the amount of time spent on various activities. However, work sampling also may be used to measure down time. The methods for applying each technique are described in the following apragraphs.

8.2.3.1 <u>Continuous Monitoring</u> - The basic technique is to have an impartial observer record times, using a stop watch, from the beginning to the end of a maintenance task. In addition to time, a description of the type of work accomplished during each element of the task is recorded. It is necessary then, that the elements of a maintenance task be clearly defined before a field measurement program is instituted. These elements may be gross divisions or finite actions depending on the level of detail desired. It is also necessary to establish bounds as to what tasks and what elements will be measured so that the observer does not waste time gathering un-needed data. If more than one technician is performing a task, each may be coded and the task elements recorded for each technician. A form for recording information as the task is accomplished and a summary form are illustrated in Appendix III. The instructions for using these forms are also contained in Appendix III. These forms were designed for ease of recording data and to facilitate data analysis.

8.2.3.2 <u>Work Sampling</u> - This is a technique whereby the activities of men and/or machines can be measured to within specified limits by sampling rather than by continuous observation. There are essentially five steps in performing a work sampling study:

    a. Decide on categories for classification of the activities

    b. Determine the number of observations to be made for the degree of accuracy desired

    c. Develop randomized observation times

    d. Design the necessary forms

    e. Observe and record data

The following paragraphs describe how each of these steps is applied to the collection of maintenance data.

8.2.3.2.1 Work sampling may be used to gather data on either maintenance technician activities or on equipment status. The following is an example of a list of activities used for technicians:

    a. Equipment maintenance

    b. On-the-job training

    c. Administrative duty

    d. Non-productive

    e. Temporary duty

Those activities may be subdivided to get the desired degree of detail for example, equipment maintenance may be divided into corrective or preventive, echelons, or, type of equipment (prime, ancilliary, test, etc.). Equipment activities would include: operational, stand-by, out of service, and off. This technique may also be used to get a cross section of any maintenance activity of interest.

8.2.3.2.2 To determine the number of observations required it is first necessary to decide which of the categories will probably take the least amount of time and then estimate the percent of the time this category will occur. The necessary sample size may then be determined by solving the following equation:

$$\text{Allowable error} = X_c \sqrt{\frac{pq}{N}} \qquad (8.1)$$

where:

X_c = confidence interval in terms of standard errors

p = percent of time activity occurs

q = 1-p

N = number of observations

The allowable error is the amount of deviation between the sample and the actual percent occurance that can be tolerated. The confidence interval is the number of standard deviations for a normal distribution that would encompass the desired confidence level (i.e., ± 2 would encompass approximately 95 percent of all observations, hence a 95 percent confidence level.) For 95 percent confidence, equation 8.1 reduces to:

$$N = \frac{4pq}{(\text{allowable error})^2} \qquad (8.2)$$

8.2.3.2.3 The number of observations to be made per day is found by dividing the total sample by the number of days allotted to the study. (Sufficient time must be allotted so that the number of daily observations do not overtax the observer.) The times for the observations are selected randomly with a different set of times for each day. Any valid method for randomizing the observations (selecting number from a hat or a table of random numbers) may be used. The times which are selected by this procedure are the times at which the observer will make his observations and record the activity in which the technician or equipment is engaged at that instant.

8.2.3.2.4 In order to record the activities and the times at which they occur, it is necessary to design special forms. These forms should contain all necessary identifying information (equipment, technician, site, etc.) and allow room for explanitory comments. The final step is for an observer to be trained in the techniques of work sampling and for him to record the activities that occur at the times previously selected.

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8.3 Administration Procedures

A field data acquisition program must be carefully planned
and controlled. The first step is to detail the prime
objectives of the program and establish the limitations.
It is then necessary to develop data collection forms for
recording the desired information. Depending on the data
collection technique to be used, either an observer training
program or a field personnel indoctrination program must
be developed. Finally, procedures for gathering data and
for program control must be established.

8.3.1 **Development of Forms** - Data forms must be carefully
designed to insure that all pertinent facts are obtained
in accordance with established guidelines and limitations.
It is important that forms be as simple and clear as
possible to assure that they will not be misinterpreted
or not fully completed. The planned analysis methods
should be considered so that data is gathered in a form
that is easily used. It is often useful to develop two
sets of forms, one to be used as a work sheet for
conviently gathering data and another for summarizing this
data, when time permits, for easy analysis.

8.3.1.1 **Types of Forms** - Forms may be developed to obtain
background data, maintenance measurements, and quality
judgements. Background data include: equipment status,
support system description, personnel complement, natural
environment, and other factors affecting the maintenance
of installed equipment. Maintenance measurements include
down time, technician time, maintenance schedules, operation
and support costs, maintenance rates, and accuracy.
Condition and usefulness of support equipment, adequacy
of maintenance personnel, and other conditions affecting
equipment maintenance, are examples of quality judgements.
Each form should be designed to most easily record the
particular type of data to be gathered.

8.3.1.2 **Typical Forms** - In the course of the maintainability
research program, many different forms were developed for
gathering field and laboratory data. The most useful of
these forms are illustrated in Appendix III, "Maintenance
Data Forms," along with instructions for their use. The
checklists from which scores were obtained for recording
in the illustrated score sheets are given in Appendix I,
"Scoring Checklists."

8.3.2 **Personnel Familiarization** - If field observer
personnel are to be used, it is necessary that they be
trained to understand basic maintainability concepts and to
accurately derive and record the desired data. If the data
are to be obtained from the personnel performing equipment
maintenance, they must be indoctrinated in the use of the
data collection forms and be motivated to be complete and
accurate in their reporting. The following paragraphs
describe the necessary ingredients for each type of pro-
gram.

8.3.2.1 **Observer Training Program** - The personnel
selected to gather maintainability data from field
installations must be familiar with equipment maintenance
and the technique to be used to obtain the desired data.
These personnel should be instructed in maintainability
theory, personal conduct at the sites, administrative
procedures, data collection techniques, and data form
completion. It is very desirable that the personnel selected
for observers have some equipment maintenance experience
and be familiar with the type of equipment to be investigated.

8.3.2.2 **Field Personnel Indoctrination** - When the desired
data is to be reported by the personnel actually performing
maintenance on the equipment, they should be advised of the
importance of the study and have a thorough understanding
of the background information. In addition, they should be
familiarized with the requirements for completing each data
form and be impressed with the need for complete and accurate
reporting. As the program progresses, periodic checks
should be made to determine if the original instructions
are being carried out.

8.3.3 **Program Implementation** - To carry out a field pro-
gram, all reporting procedures and necessary scheduling
should be completed in advance of the actual field data
collection. The analysis procedures should be determined
so that preliminary analysis may be performed as the
data is received. Progress reporting and periodic
checks should be used to determine the current status of
the program. In addition, the initial reports should be
reviewed for possible improvement in format or reporting
procedures.

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8.4 Data Analysis

The final step in a field data acquisition program is to
analyze the data collected and determine the relations
between the factors measured. The basic ingredients of
data analysis are screeing, summarizing, and mathematical
analysis. The purpose of the analysis is to get meaningful
information and relations for use in specifying, designing,
and planning for maintainability.

8.4.1 Screening - The data from the field should be re-
viewed for completeness and accuracy as soon as possible
after receipt. If any discrepancies are detected, the
information will still be fresh in the mind of the reporter
and can be easily corrected. The screener should also
try to detect the possibility of data not being reported.
Through the screening process, the progress of the program
is monitored and any necessary changes in the quantity or
type of data to be gathered may be instituted at the
earliest possible time. During screening, preliminary
analysis may also be made to determine the probability of
obtaining the desired results, and the program may be re-
directed if necessary.

8.4.2 Summary and Analysis - At the completion of the
collection of data in the field and after the data has been
completely screened, a summary is made. The summary consists
of totals and averages for the factors measured in addition
to frequency distributions and comparisons between categories
(equipment, sites, etc.). This initial summary provides
the basis for determining what factors to investigate and
what mathematical techniques to use. The mathematical
analysis consists of computing indices from the data and
determining relations between or among various factors.
The procedures for calculating maintenance indices are
given in Section 2, "Maintenance Theory and Classification,"
and techniques for determining factor relations are given
in Appendix II, "Mathematical Formulas."

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GLOSSARY

1. <u>Availability</u> - The probability that a system or equipment is operating satisfactorily at any point in time when used under stated conditions. This is further classified as:

    a.   <u>Inherent Availability</u> (A_i) - The probability that a system or equipment, when used under stated conditions in an ideal supply environment, shall operate satisfactorily at any given time. A_i excludes ready time, supply down time, and waiting or administrative time. It may be expressed as:

$$A_i = \frac{t'_s}{t'_s + t'_r} = \frac{MTBF}{MTBF + MDT} \text{, where}$$

       t'_s = mean failure free operating time, and

       t'_r = mean active maintenance down time

    b.   <u>Operational Availability</u> (A_O) - Is the probability that a system or equipment, when used under stated conditions in an actual supply environment, shall operate satisfactorily at any given time.

$$A_O = \frac{t_s}{t_s + t_r}$$

Where

t_s = total mean failure free operating time and ready time,

and

t_r = mean downtime including supply downtime and waiting or administrative time.

    c. <u>Use Availability</u> - The system or equipment availability calculated on a calendar time basis which includes the time the system (equipment) is not needed for use (off-time), in addition to operate time and total down time.

2. <u>Capability</u> - The ability of a system or equipment to perform its required mission. This includes the level of performance achieved and the dependability of operation.

3. <u>Complexity</u> - The number and correlation of functional units (such as circuits) contained in a system or equipment.

4. <u>Corrective Maintenance</u> - The maintenance performed on a non-scheduled basis to restore equipment to a satisfactory condition by providing correction of a failure which has caused degradation to the equipment below its specified performance.

5. <u>Environment</u> - The external conditions which directly or indirectly affect the operation of equipment. This is further defined as follows:

    a. <u>Physical Environment</u> - The conditions usually caused by nature; i.e., temperature, humidity, dust, etc.

    b. <u>Support Environment</u> - The conditions attributable to the maintenance organization; i.e., condition of test equipment, personnel proficiency, etc.

6. <u>Failure (Fault, Malfunction)</u> - A failure is an occurrence, either catastrophic or gradual deterioration, which causes the performance of the equipment to deviate from specified limits, as detailed in the equipment specification. It is a condition which requires the services of maintenance personnel to restore the equipment to satisfactory condition.

7. <u>Maintainability</u> - The combined qualitative and quantitative characteristics of material design and installation which enables the accomplishment of operational objectives with minimum expenditures including manpower,

personnel skill, test equipment, technical data, and facilities under operational environmental conditions in which scheduled and unscheduled maintenance will be performed.

8. <u>Maintainability Factor</u> - See Maintainability Parameter.

9. <u>Maintainability Parameter</u> - A group of factors and/or environmental, human and design features which affect the performance of maintenance on an equipment.

    a. <u>Design</u> - This encompasses all the design features of the equipment. It covers the physical aspects of the equipment itself, requirements for test equipment and tools, training and personnel skill levels required to do maintenance as dictated by design, packaging, test points, accessability, and other factors internal to the equipment.

    b. <u>Personnel</u> - This includes the skill level of the maintenance men, their attitudes, experience, technical proficiency, and other human factors which are usually associated with equipment maintenance.

    c. <u>Support</u> - This area covers logistics and maintenance organization involved in maintaining a system. A short breakdown of support would include tools and test equipment on hand at a particular location, the availability of manuals and technical orders associated with the equipment, the particular supply problems which exist at a site, and, finally, the general maintenance organization.

10. <u>Maintenance</u> - All actions necessary for the retaining of material in, or restoring it to, a serviceable condition. Maintenance includes servicing, repair, modification, modernization, overhaul, inspection, and condition determination.

11. <u>Maintenance (Support) Cost</u> - The overall expenditure incurred in the sustainment of a military electronic system. This expenditure is composed of the following:

   a.   <u>Manpower Costs</u>
       Maintenance personnel
       Administrative personnel

   b.   <u>Facilities Costs</u>
       Maintenance
       Personnel

   c.   <u>Test Equipment Costs</u>
       Initial Cost
       Test equipment maintenance

   d.   <u>Supply Costs</u>
       Spares
       Tools

   e.   <u>Training Costs</u>
       Training school
       On-the-Job Training

12. <u>Maintenance Element</u> - A discrete portion of a maintenance task which can be described and measured in terms of time.

13. <u>Maintenance Level</u> - The type of organization and the area where maintenance is performed.

   a.   <u>Organizational</u> - Maintenance performed directly on an equipment, or in the immediate vicinity, by the using activity.

   b.   <u>Field</u> - Maintenance performed at the equipment installation by a highly skilled repair team using specialized test equipment.

   c.   <u>Depot</u> - Maintenance performed at a remote facility, equipped to handle complex repairs and to completely overhaul equipment.

14. <u>Maintenance Proficiency</u> - A maintenance technician's ability to use and apply the skills, concepts and principles necessary for equipment maintenance.

15. **Maintenance Task** - A maintenance task is defined as any single or series of manipulative actions required to preclude the occurrence of a failure or restore an equipment to satisfactory operation condition.

16. **Mean** - The sum of a set of values divided by the total number comprising the set.

17. **Modularization** - A design concept where associated parts are packaged in removable groups. These groups can be in the form of printed circuits or mounted in individual packages with an associated connector.

18. **95th Percentile** - A value which will encompass 95% of all times under consideration. For example, if a value of 80 minutes was given, this would indicate that 95% of all observed times would fall between 0 and 80 minutes.

19. **Operational Readiness** - The probability that at any point in time a system or equipment is either operating satisfactorily or ready to be placed in operation on demand when used under stated conditions, including stated allowable warning time.

20. **Operation Profile** - The various equipment operating phases; i.e., calendar time, off time, scheduled time, operate time, downtime. These phases may be developed further as:

    a. **Calendar time** - The total number of calendar hours in a designated period of observation.

    b. **Off time (Free Time)** - The number of calendar hours when the equipment is not needed for its intended use.

    c. **Scheduled Time** - The number of calendar hours that the equipment is required for operation; the calendar time minus off time.

    d. **Operate Time** - The number of calendar hours during which the equipment is performing its intended

function; the scheduled time minus down time.

e. <u>Down Time</u> - (See 26)

21. <u>Preventive Maintenance</u> - That maintenance performed to maintain a system or equipment in satisfactory operational conditions, by providing systematic inspection, detection, and correction of incipient failures before they occur or develop into major failures.

22. <u>Reliability</u> - The probability that the system will perform satisfactorily for a given period of time when used under stated conditions.

23. <u>Repairability</u> - The probability that when maintenance action due to equipment failure is taken, the system will be restored to a satisfactory operating condition in a given period of time.

24. <u>Skill Levels</u> - The classification system used to rate maintenance personnel as to their relative abilities to perform maintenance.

25. <u>System Effectiveness</u> - The probability that an equipment design will provide maximum capability for the least total cost, in terms of resources required.

26. <u>Total Down Time</u> - The number of calendar hours that a system is not available for use, including time for active maintenance, both corrective and preventive; supply down time due to unavailability of a needed item; and waiting or administrative time, during which work is not being done on the system. Total Down Time may be defined further as Active Down Time and Delay Time as follows:

a. <u>Active Down Time</u> - Down time during which work is being done on the system. This includes that time required for both corrective and preventive maintenance, reported separately.

b. <u>Delay Down Time</u> - Down time during which work is not being done on the system. This should not be included as a factor in determining maintainability except in those instances where a requirement

exists for skills or skill levels above normal,
or where a requirement exists for special equip-
ment or tools.

27. Total Technician Time - The total man-minute expen-
diture required to complete a maintenance task; to in-
clude Active Technician Time and Delay Technician Time.
These may be defined as follows:

    a. Active Technician Time - The number of man-minutes
       expended in active performance of a maintenance
       task.

    b. Delay Technician Time - The number of man-minutes
       expended by maintenance men assigned to a task
       while not actively engaged in performing maintenance.

28. Troubleshooting - The locating and diagnosing of
malfunctions or break downs in equipment by means of sys-
tematic checking or analysis; e.g., using automatic test
equipment to identify a specific faulty unit, or analyzing
the measuring of malfunction symptoms by logical analysis
of data flow diagrams. Some troubleshooting approaches
are as follows:

    a. Half-split

    b. Middle to trouble

    c. Input to output

    d. Output to input

    e. Non-sequential or random

APPENDIX I

SCORING CHECKLISTS

APPENDIX I

TABLE OF CONTENTS

APPENDIX I

SCORING CHECKLISTS

1. INTRODUCTION

This appendix contains the checklists used for scoring the maintainability design conditions leading to the down time predictions. Criteria or guidelines for scoring are also presented.
(The summary forms used to accumulate these data are presented in APPENDIX III.)

2. DESIGN CHECKLISTS

The maintainability features of equipment design are appraised by the use of three checklists designated as A, B, and C. The presentation and discussion of each follows.

2.1 CHECKLIST A - SCORING PHYSICAL DESIGN FACTORS

The intent of this checklist is to determine the impact of equipment packaging, physical layout, etc., upon maintenance time. Data analysis reveals that the aspects considered by this checklist exhibit the greatest influence upon maintenance time. Consequently, particular attention must be exercised during the completion of this checklist.

2.1.1 Discussion - Questions 1 through 4 consider access, both internal and external, in association with facility with which it can be gained. The external aspect relates to covers, panels, drawers, etc., which appear on the periphery of the equipment. Shields, safety enclosures, etc., would come under evaluation when considering the internal portion.

2.1.1.1 Methods of securing modules, components, and parts are of concern in questions 5 and 6. These questions would be rated with respect to the part assumed failed in association with other units which may come under surveillance in the course of the troubleshooting action. Since testing of some part types requires removal from the circuit, the facility with which this may

be accomplished is important. Also, the time required to replace the defective unit is of concern.

2.1.1.2 Questions 7 through 11 relate to securing maintenance information required to diagnose logically the defective part. Examination of maintenance data has provided that this element of time contributes more than 50 percent to total maintenance requirements. The intent of this series of questions is to determine the relative ease with which the needed data may be secured. Further, it is to be determined if this data is supplied directly by the equipment through built-in indicators or test equipment, or if external test devices are required. Additionally, identification and labelling of test points and parts are assessed because of their contribution to the diagnostic process.

2.1.1.3 Question 12 determines the need for circuit adjustments. Such adjustments can be time consuming, hence this area is of vital importance. The ability to test the defective part without removal from the circuit is determined by question 13. The facility to accomplish in-circuit testing will further aid the maintenance process.

2.1.1.4 Questions 14 and 15 consider protective devices and safety precautions which must be exercised by maintenance personnel. Safety shields, interlocks, etc., are necessary precautionary devices which must be provided in equipment possessing hazards such as high voltage, x-rays, etc. Although they are necessary, their presence will slow the maintenance task accomplishment. Consequently, such situations must be appraised.

2.1.2 Checklist A, Scoring Physical Design Factors

1. Access (External)

    a. Access adequate both for visual and manipulative tasks (electrical and mechanical)................... 4

    b. Access adequate for visual, but not manipulative, tasks... 2

    c. Access adequate for manipulative, but not visual, tasks... 2

    d. Access not adequate for visual or manipulative tasks... 0

---

2. Latches and Fasteners (External)

    a. External latches and/or fasteners are captive, need no special tools, and require only a fraction of a turn for release......................... 4

    b. External latches and/or fasteners meet two of the above three criteria............................... 2

    c. External latches and/or fasteners meet one or none of the above three criteria........................ 0

---

3. <u>Latches and Fasteners</u> (Internal)

    a.   Internal latches and/or fasteners are captive, need no special tools, and require only a fraction of a turn for release.......................... 4

    b.   Internal latches and/or fasteners meet two of the above three criteria................................ 2

    c.   Internal latches and/or fasteners meet one or none of the above three criteria........................ 0

                                                                —

4. <u>Access</u> (Internal)

    a.   Access adequate both for visual and manipulative tasks (electrical and mechanical)................... 4

    b.   Access adequate for visual, but not manipulative, tasks... 2

    c.   Access adequate for manipulative, but not visual, tasks... 2

    d.   Access not adequate for visual or manipulative tasks... 0

5. <u>Packaging</u>

    a.   Internal access to components and parts can be made with no mechanical disassembly...................... 4

    b.   Little disassembly required (less than 3 min.)...... 2

    c.   Considerable disassembly is required (more than 3 min.)... 0

6. Units - Parts (Failed)

    a. Units or parts of plug-in nature................... 4

    b. Units or parts of plug-in nature and mechanically
       held... 2

    c. Units of solder-in nature......................... 2

    d. Units of solder-in nature and mechanically held.... 0

7. Visual Displays

    a. Sufficient visual information on the equipment is
       given within one display area...................... 4

    b. Two display areas must be consulted to obtain
       sufficient visual information...................... 2

    c. More than two areas must be consulted to obtain
       sufficient visual information...................... 0

8. **Fault and Operation Indicators** (Built-In Test Equipment)

   a. Fault or malfunction information is provided clearly and for rapid action................................. 4

   b. Fault or malfunction information clearly presented, but requires operator interpretation................. 2

   c. Fault or malfunction information requires no operator interpretation, but is not clearly presented... 2

   d. Fault or malfunction information not clearly presented and requires operator interpretation........ 0

                                               ———

9. **Test Points** (Availability)

   a. Task did not require use of test points............. 4

   b. Test points available for all needed tests.......... 3

   c. Test points available for most needed tests......... 2

   d. Test points not available for most needed tests..... 0

                                               ———

10. **Test Points** (Identification)

   a. All test points are identified with required readings given....................................... 4

   b. Some are suitable marked............................ 2

   c. Points are not marked and test data is not given.... 0

                                               ——

11. **Labelling**

   a. All parts labelled with full identifying information and all identifying information clearly visible... 4

   b. All parts labelled with full identifying information, but some information hidden................... 2

   c. All information visible, but some parts not fully identified.. 2

   d. Some information hidden and some parts not fully identified.. 0

12. **Adjustments**

   a. No adjustments or realignment are necessary to place equipment back in operation.................. 4

   b. A few adjustments, but no major realignments are required... 2

   c. Many adjustments or major realignments must be made.. 0

13. **Testing** (In Circuit)

   a. Defective part or component can be determined without removal from the circuit...................... 4

   b. Testing requires removal........................... 0

14. **Protective Devices**

    a. Equipment was automatically kept from operating
after malfunction occurred to prevent further dam-
age. (This refers to malfunction of such areas as
bias supplies, keep-alive voltages, etc.)........... 4

    b. Indicators warned that malfunction has occurred..... 2

    c. No provision has been made......................... 0

                                    —————

15. **Safety** (Personnel)

    a. Task did not require work to be performed in close
proximity to hazardous conditions (high voltage,
radiation, moving parts and/or high temperature
parts)... 4

    b. Some delay encountered because of precautions
taken... 2

    c. Considerable time consumed because of hazardous
conditions.. 0

                                    —————

2.1.3 Scoring Criteria

ITEM NO. 1 **EXTERNAL ACCESS**

Determines if the external access is adequate for visual
inspection and manipulative actions. Scoring will apply
to external packaging as related to maintainability de-
sign concepts for ease of maintenance. This item is
concerned with the design for external visual and manip-
ulative actions which would precede internal maintenance
actions.

Scoring Criteria

a. To be scored when the external access, while visual
and manipulative actions are being performed on the ex-
terior of the subassembly, does not present difficulties
because of obstructions (cables, panels, supports, etc.)

b. To be scored when the external access is adequate
(no delay) for visual inspection, but not for manipulative
actions. External screws, covers, panels, etc., can be
located visually; however, external packaging or obstruct-
tions hinders manipulative actions (removal, tightening,
replacement, etc.).

c. To be scored when the external access is adequate
(no delay) for manipulative actions, but not for visual
inspections. This applies to the removal of external
covers, panels, screws, cables, etc., which present no
difficulties; however, their location does not easily
permit visual inspection.

d. To be scored when the external access is inadequate
for both visual and manipulative tasks. External covers,
panels, screws, cables, etc., cannot be easily removed
nor visually inspected because of external packaging or
location.

ITEM NO. 2 LATCHES AND FASTENERS (EXTERNAL)

Determines if the screws, clips, latches, or fasteners
outside the assembly require special tools, or if signi-
ficant time was consumed in the removal of such items.
Scoring will relate external equipment packaging and
hardware to maintainability design concepts. Time consumed
with preliminary external disassembly will be propor-
tional to the type of hardware and tools needed to release
them and will be evaluated accordingly.

Scoring Criteria

a. To be scored when external screws, latches, and
fasteners are:

(1) Captive
(2) Do not require special tools
(3) Can be released with a fraction of a turn

Releasing a "DZUS" fastener which requires a 90 degree turn using a standard screw driver is an example of all three conditions.

b.   To be scored when external screws, latches, and fasteners meet two of the three conditions stated in (a) above.   An action requiring an Allen wrench and several full turns for release shall be considered as meeting only one of the above requirements.

c.   To be scored when external screws, latches, and fasteners meet only one or none of the three conditions stated in (a) above.

ITEM NO. 3   LATCHES AND FASTENERS (INTERNAL)

Determine if the internal screws, clips, fasteners, or latches within the unit require special tools, or if significant time was consumed in the removal of such items.   Scoring will relate internal equipment hardware to maintainability design concepts.   The types of latches and fasteners in the equipment and standardization of these throughout the equipment shall tend to affect the task by reducing or increasing required time to remove and replace them.   Consider "internal" latches and fasteners to be within the interior of the assembly.

Scoring Criteria

a.   To be scored when internal screws, latches and fasteners are:

(1) Captive
(2) Do not require special tools
(3) Can be released with a fraction of a turn

Releasing a "DZUS" fastener which requires a 90 degree turn using a standard screw driver would be an example of all three conditions.

b. To be scored when internal screws, latches, and fasteners meet two of the three conditions stated in (a) above. A screw which is captive can be removed with a standard or Phillips screw driver, but requires several full turns for release.

c. To be scored when internal screws, latches, and fasteners meet one of three conditions stated in (a) above. An action requiring an Allen wrench and several full turns for release shall be considered as meeting only one of the above requirements.

ITEM NO. 4 ACCESS (INTERNAL)

Determines if the internal access is adequate for visual inspection and manipulative actions. This item applies to internal packaging concepts in relation to design for ease of maintenance. Internal is to mean all work accomplished after gaining access to some portion of the equipment.

Scoring Criteria

a. To be scored when the internal access, while performing manipulative or visual actions in a sub-assembly or unit, does not present difficulties because of the internal construction or part location.

b. To be scored when the internal access is adequate (no delay) for visual inspection, but not for manipulative actions. Components and parts can readily be located visually during the maintenance task; however, internal construction or part location hampers manipulative actions (testing, removal, etc.).

c. To be scored when the internal access is adequate for manipulative actions, but not for visual inspections. Components or parts can be easily tested or removed; however, their physical location does not easily permit visual inspection.

d. To be scored when internal access is inadequate for both visual and manipulative tasks. Components or parts

cannot be easily tested or identified because of internal construction or location during the maintenance action.

ITEM NO. 5 PACKAGING

Determines the access (within the sub-assembly) to components or parts requiring mechanical disassembly. This question concerns itself with the internal packaging of parts relative to the maintenance action. Current design concepts have been concentrated on module type packaging; however, even these vary in a mechanically held module, while others are plug-in type only. This item deals with the mechanical problems involved in gaining access to failed components or parts.

Scoring Criteria

a. To be scored when less than one minute is required to gain access to the failed component or part.

b. To be scored when less than three minutes is expended in gaining access to the failed component or part.

c. To be scored when more than three minutes is expended in gaining access to the failed component or part.

ITEM NO. 6 UNITS - PARTS

Determines the manner in which units or parts are removed or replaced during the maintenance action. Since units and parts are electrically and/or mechanically secured in equipments in many different ways, the time to remove such items varies considerably. Mechanically held items include tubes protected from vibrations by special shields or clamps, printed boards clipped into their sockets, and parts and components held by brackets. Soldered items include resistors, capacitors, etc.

Scoring Criteria

a. To be scored when units or parts are plug-in types requiring only to be pulled out. Plug-in type parts such as tubes, some relays, crystals, etc., would be included in this category .

b. To be scored when units or parts are plug-in types,
but are mechanically held by clips, shields, clamps, etc.
Also applies to maintenance requiring the removal of a
tube having external grid or plate connections, anti-
vibration shields, etc.

c. To be scored when units or parts are soldered-in
types such as resistors, capacitors, etc. When the removal
of parts requires the unsoldering of part terminations.

d. To be scored when units or parts are soldered-in
mechanically held types such as transformers, jacks, etc.
The removal or replacement of parts requires mechanical
disassembly and unsoldering.

ITEM NO. 7 VISUAL DISPLAYS

Determines if sufficient visual information pertaining to
the equipment malfunction is displayed within one area or
unit. Circuit indicators and meters provide, to some ex-
tent, symptom analysis. Therefore, it is important that
these indications be displayed within one area to insure
rapid analysis and action. If several areas must be con-
sulted before a qualified estimation of the difficulty
can be made, much time is required.

Scoring Criteria

a. To be scored when visual information associated with
the fault or malfunction is displayed within one area.
Applicable if diagnosis and repair can be accomplished
successfully following symptoms derived from one display
area or sub-assembly of the system.

b. To be scored when two display areas must be consulted
to provide visual information associated with the fault
or malfunction. Two separate display areas on the system
(meter panel and fault indicators) must be consulted to
diagnose malfunctions successfully.

c. To be scored when more than two areas or sub-assemblies
must be consulted to provide visual information associated

with the fault or malfunction. This would be indicative
of a least maintainable condition.

ITEM NO. 8 <u>FAULT AND OPERATION INDICATORS
(BUILT-IN TEST EQUIPMENT)</u>

Determines if an equipment malfunction or fault is clearly
discernable via audible alarms, indicators, etc., and that
such information is clearly presented for rapid maintenance
action. The use of indicators is increased as complexity
increases, and equipment availability becomes more impor-
tant. Although visual and audio alarms usually indicate
that a problem exists, they do not always determine the
exact location of the malfunction. The more precise the
indication, the better the maintenance condition.

<u>Scoring Criteria</u>

a. To be scored when an equipment fault or malfunction
occurs and is evidence by alarms, indicators, etc., which
provide for rapid diagnosis and maintenance action. An
example of this would be when a power supply failure occurs
because of an open fuse which is pointed out by an in-
dicator or alarm.

b. To be scored when an equipment fault or malfunction
occurs and is evidenced by alarms, indicators, etc., but
requires further tests for isolation of the fault. Loss
of output power is evidenced by an alarm; however, further
diagnosis must be made to determine the exact cause of
trouble.

c. To be scored when an equipment fault or malfunction
occurs and is not clearly determined by alarms, indicators,
etc.; however, provisions for rapid diagnosis and main-
tenance action are available. Applies when some pre-
liminary testing might be required to determine if a fault
or malfunction such as the loss of some voltage, (B+,
Bias, etc.) exists. Once determined, however, maintenance
is expedited, such as in the case of an open fuse.

d. To be scored when an equipment fault or malfunction
occurs and is not clearly discernable, and which requires

symptom interpretation. Testing is also necessary to determine the equipment status and cause of failure.

ITEM NO. 9 TEST POINTS AVAILABILITY

Determines if test points are available for needed tests pertaining to the maintenance action. A test point shall be considered as any test probe receptacle where specific system operation data can be obtained. This definition eliminates as test points connector pins on printed circuit boards, terminals, tube pins, etc. The number of test points available and the amount of information yielded will affect the time to establish the cause and location of the fault.

Scoring Criteria

a.   To be scored when the maintenance action did not require the use of test points, but when, instead, the malfunction can be diagnosed and repaired via built-in test equipment.

b.   To be scored when all needed tests were accomplished at test points. Sufficient information to diagnose and repair the trouble was available at test points.

c.   To be scored when at least 51% of the required tests were accomplished at test points. Troubleshooting required that several separate tests, most of which made use of test points, had to be made.

d.   To be scored when the majority of needed tests were not accomplished at test points. Malfunction diagnosis and repair required the making of tests for which few or no test points were available.

ITEM NO. 10 TEST POINT IDENTIFICATION

Determines if all test points required during the maintenance action are properly identified by circuit symbol and pertinent test data. This precise information provides diagnostic data to aid in troubleshooting the malfunction.

<u>Scoring Criteria</u>

a. To be scored when all test points needed for task completion are identified (circuit symbol), with required readings given (+6VDC, -18VDC, 115VAC, etc.). This is indicative of a best maintainable condition.

b. To be scored when the majority of test points required for task completion are suitable identified.

c. To be scored when test points required for task completion are not suitable identified. Troubleshooting at test points is a cause for delay because required voltage readings, signal characteristics, etc., are not specified. This would indicate that a least maintainable condition exists.

ITEM NO. 11 <u>LABELLING</u>

Determines if parts associated with the maintenance actions are identified with respect to circuit symbol and part identification. Proper identification of parts can be an important asset to the maintenance task in that, if part circuit number is omitted from the equipment, considerable time could be wasted tracing the circuit to identify it. Similarily, if information is "hidden," requiring removal of other parts to read it, much time will be consumed.

<u>Scoring Criteria</u>

a. To be scored when all parts associated with the maintenance action are identified and this information is clearly visible. To include testing or removing of parts that are clearly identified (V401-6BE6) or (R-1225-400 ～).

b. Applies when all parts associated with the maintenance action are identified, but some of this information is not visible. Applies to testing or removing parts that are labelled, but which information is hidden by obstructions.

c. Applicable when all circuit symbols are visible, but

some parts associated with the tasks are not identified. Parts required for testing or removal are not identified with reference to part value, etc.

d. To be scored when some parts associated with the maintenance task contain hidden circuit symbols and are not fully identified. Parts required in testing or removal are not identified and information is also hidden.

ITEM NO. 12 **ADJUSTMENTS**

Determines if adjustments such as tuning and alignment are required, after a maintenance action, to make the equipment operate according to specifications. An adjustment will be any action which resets or changes variable components such as potentiometers, variable capacitors, slug-tuned coils, etc., whereby the operation of the system assembly or subassembly is affected. These actions, depending upon their criticality and frequency, will affect the overall maintenance time.

Scoring Criteria

a. To be scored when no adjustments are required to bring the equipment back to normal operating specifications. Applies to repair of the malfunction, if the equipment need only be turned on.

b. To be scored when a few adjustments of a minor nature are required to place equipment back in operation according to specifications.

c. To be scored when many adjustments (time-consuming) or a major tuning or alignment is required to place equipment back to normal operating specifications.

ITEM NO. 13 **TESTING (IN CIRCUIT)**

Determines if the defective component or part can be tested without removal from the circuit. This question is based on the nature of the equipment and the repair concepts associated with the particular design.

Scoring Criteria

a. Applicable when the component or part can be decisively determined as being defective without removal of any part from the circuit.

b. To be scored when the component or part must be removed from the circuit to be decisively determined as defective. When testing has isolated the trouble to a particular part or component, however, a definite opinion cannot be made until such part or component is electrically or physically removed from the circuit for further testing.

ITEM NO. 14 PROTECTIVE DEVICES

Encompasses equipment design provisions for self-protection against damage to components or parts after a malfunction has occurred. If a system has protection devices such as fuses, circuit breakers, etc., then the equipment can be protected from further damage as well as aiding in isolating the malfunction. If no provisions have been made, further damage and increased repair time could result.

Scoring Criteria

a. To be scored when automatic shut-off devices protected parts or components from further damage after a malfunction occurred in a critical area. A typical example of such a malfunction would be if the Bias supply fails and B+ voltage is automatically cut off by circuit breakers, fuses, or relay action.

b. To be scored when automatic shut-off devices do not protect parts or components from further damage, but when visual indicators or audible alarms warn personnel of the situation.

c. To be scored when a critical malfunction occurs and parts or components are not protected by automatic shut-off devices, indicators, or alarms. Involves malfunction which damages parts or components because automatic shut-off devices or alarms were not provided.

ITEM NO. 15 SAFETY (PERSONNEL)

Determines if the maintenance action requires personnel
to work under hazardous conditions such as close proximity
to high voltage, radiation, moving parts, high temperature
components, or on elevated structures, etc.

Scoring Criteria

a. To be scored when the maintenance action did not re-
quire personnel to work under hazardous conditions. The
maintenance action did not require precautions to be
taken, in that the task was not associated with high vol-
tage, moving parts, etc.

b. To be scored when precautions were taken because of
hazardous conditions causing slight delays in the main-
tenance action. A typical example would be when a shorting
probe must be used to discharge high voltage capacitors.

c. To be scored when precautions taken because of hazard-
ous conditions caused a considerable delay to the main-
tenance action. Maintenance required that testing be done
in close proximity to high voltage where extreme caution
was necessary, or the closeness of moving parts (gears,
motors, etc.), caused delay because of precautions taken.

2.2 CHECKLIST B - SCORING DESIGN DICTATES-FACILITIES

The intent of this questionnaire is to determine the need
for external facilities. Facilities, as used here, in-
clude material such as test equipment, connectors, etc.,
and technical assistance from other maintenance personnel,
supervisor,etc.

2.2.1 Discussion - Questions 1 through 3 evaluate the material
requirement. Such requirements can best be determined from
a maintenance analysis of the assumed task. This analysis
will establish the need for test equipment and other materials.

2.2.1.1 Technical assistance requirements are evaluated
by questions 4 through 7. Evaluation of these questions

can best be accomplished by viewing task requirements
as imposed by the equipment with respect to the typical
technician's capabilities. It has been found that the
average Air Force technician is a high school graduate
who has had 20 to 36 weeks of training in electronic funda-
mentals and specialized equipment. He receives additional
on-the-job training after being assigned to a field main-
tenance activity. On the average, he is 24 years old and
has been in the service 4.6 years. His attitude and moti-
vation toward his job have been found to be satisfactory.
Specific experience on the assigned equipment was noted to
be 1.3 years. Reviewing detailed analysis of maintenance
tasks performed by Air Force technicians has provided that
a logical or systematic approach to the defective part
normally is not used. The equipment task requirements for
personnel viewed within this framework should permit
effective scoring of this checklist.

2.2.2 Checklist B, Scoring Design Dictates-Facilities

1. **External Test Equipment**

    a. Task accomplishment does not require the use of
        external test equipment............................. 4

    b. One piece of test equipment is needed.............. 2

    c. Several pieces (2 or 3) of test equipment are
        needed... 1

    d. Four or more items are required.................... 0

2. <u>Connectors</u>

    a. Connectors to test equipment require no special tools, fittings, or adapters......................... 4

    b. Connectors to test equipment require some special tools, fittings, or adapters (less than two)........ 2

    c. Connectors to test equipment require special tools, fittings, and adapters (more than two).............. 0

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3. <u>Jigs or Fixtures</u>

    a. No supplementary materials are needed to perform task... 4

    b. No more than one piece of supplementary material is needed to perform task........................... 2

    c. Two or more pieces of supplementary material are needed... 0

---

4. <u>Visual Contact</u>

    a. The activities of each member are always visible to the other member.................................. 4

    b. On at least one occasion, one member can see the second, but the reverse is not the case............. 2

    c. The activities of one member are hidden from the view of the other on more than one occasion......... 0

---

5. Assistance (Operations Personnel)

    a. Task did not require consultation with operations personnel.. 4

    b. Some contact was required........................... 2

    c. Considerable coordination required.................. 0

6. Assistance (Technical Personnel)

    a. Task required only one technician for completion.... 4

    b. Two technicians were required....................... 2

    c. Over two were used.................................. 0

7. Assistance (Supervisors or Contract Personnel)

    a. Task completion did not require consultation with supervisor or contract personnel.................... 4

    b. Some help needed.................................... 2

    c. Considerable assistance needed...................... 0

2.2.3 Scoring Criteria

ITEM NO. 1 EXTERNAL TEST EQUIPMENT

Determines if external test equipment is required to complete the maintenance action. The type of repair considered maintainably ideal would be one which did not require the use of external test equipment. It follows, then, that a maintenance task requiring test equipment would involve more task time for set up and adjustment and should receive a lower maintenance evaluation score.

Scoring Criteria

a. To be scored when the maintenance action does not require the use of external test equipment. Applicable when the cause of the malfunction is easily detected by inspection or built-in test equipment.

b. To be scored when one piece of test equipment was required to complete the maintenance action. Sufficient information was available through the use of one piece of external test equipment for adequate repair of the malfunction.

c. To be scored when 2 or 3 pieces of external test equipment are required to complete the maintenance action. This type malfunction would be complex enough to require testing in a number of areas with different test equipments.

d. To be scored when four or more pieces of test equipment are required to complete the maintenance action. Involves an extensive testing requirement to locate the malfunction. This would indicate that a least maintainable condition exists.

ITEM NO. 2 CONNECTORS

Determines if supplementary test equipment requires special fittings, special tools, or adapters to perform adequately tests on the electronic system or sub-system. During troubleshooting of electronic systems, the minimum need for test equipment adapters or connectors indicates that a better maintainable condition exists.

Scoring Criteria

a. To be scored when special fittings or adapters and special tools are not required for testing. This would apply to tests requiring regular test leads (probes or alligator clips) which can be plugged into or otherwise secured to the test equipment binding post.

b. Applies when one special fitting, adapter or tool is required for testing. An example would be if testing had to be accomplished using a 10 DB attenuator pad in series with the test set.

c. To be scored when more than one special fitting, adapter, or tool is required for testing. An example would be when testing requires the use of an adapter and an RF attenuator.

ITEM NO. 3 JIGS OR FIXTURES

Determines if supplementary materials such as block and tackle, braces, dollies, ladder, etc., are required to complete the maintenance action. The use of such items during maintenance would indicate the performance of a major maintenance time and pinpoint specific deficiencies in the design for maintainability.

Scoring Criteria

a. To be scored when no supplementary materials (block and tackle, braces, dollies, ladder, etc.) are required to complete maintenance. Applies when the maintenance action consists of normal testing and the removal or replacement of parts or components can be accomplished by hand, using standard tools.

b. To be scored when one supplementary material is required to complete maintenance. Applies when testing or when the removal and replacement of parts requires a step ladder for access or a dolly for transportation.

c. To be scored when more than one supplementary material is required to complete maintenance. Concerns the maintenance action requiring a step ladder and dolly adequately to test and remove the replaced parts.

ITEM NO. 4 VISUAL CONTACT

Determines if the nature of the equipment, location, or maintenance action causes the members of a team to be hidden from the view of each other at times during the task.

Scoring Criteria

a. Applies when the team members are visible to each other during the entire maintenance action.

b. To be scored if one member of the team becomes hidden from view of the other member or members during the maintenance action.

c. Applicable if team members are hidden from view on more than one occasion.

ITEM NO. 5 ASSISTANCE (OPERATIONS PERSONNEL)

Determines whether or not information or assistance from operations personnel is required, and if required, to what extent.

Scoring Criteria

a. To be scored when the maintenance action does not require the assistance of operations personnel. This would apply if physical or verbal aid to the technical personnel was not required. (Less than one minute.)

b. To be scored when the maintenance action requires a small amount of assistance from operations personnel. (One to five minutes.)

c. To be scored when the maintenance action requires considerable assistance from operation personnel in the operation or repair of the malfunctioning equipment. (Over five minutes.)

ITEM NO. 6 ASSISTANCE (TECHNICAL PERSONNEL)

Determines the number of technical personnel required to complete the maintenance action, not including administrative or operations type personnel.

Scoring Criteria

a. To be scored when only one technician was required to complete the maintenance action.

b. To be scored when two technicians were required to complete the maintenance action.

c. To be scored when more than two technicians were required to complete the maintenance action.

ITEM NO. 7 <u>ASSISTANCE (SUPERVISORS OR CONTRACTOR PERSONNEL)</u>

Determines whether or not the services of supervisor or contractor personnel (TECH. REPS.) were required to complete the maintenance action and the extent of their participation in the task.

Scoring Criteria

a. To be scored when no supervisor or contractor personnel are consulted during the maintenance action.

b. To be scored when a small amount of assistance from supervisor or contractor personnel is required to complete the maintenance action.

c. To be scored when considerable assistance from supervisor or contractor personnel is required to complete the maintenance action.

2.3 CHECKLIST C - SCORING DESIGN DICTATES-MAINTENANCE SKILLS

This checklist evaluates the personnel requirements relating to physical, mental, and attitude characteristics, as imposed by the maintenance task.

2.3.1 <u>Discussion</u> - Evaluation procedure for this checklist can best be explained by way of several examples. Consider first question 1, which deals with arm, leg, and back strength. Should a particular task require the removal of an equipment drawer weighing 100 pounds, this

would impose a severe requirement on this characteristic. Hence, in this case the question would be given a low score (0 to 1). Assume another task which, due to small size and delicate construction, required extremely careful handling. Here question 1 would be given a high score (4), but question dealing with eye-hand coordination and dexterity would be given a low score. Other questions in the checklist relate to various personnel characteristics important to maintenance task accomplishment. In completing the checklist, the task requirements for each of these characteristics should be viewed with respect to average technician capabilities.

2.3.2 Checklist C, Scoring Design Dictates-Maintenance Skills

	Score
1. Arm, Leg, and Back Strength	____
2. Endurance and Energy	____
3. Eye-Hand Coordination, Manual Dexterity, and Neatness	____
4. Visual Acuity	____
5. Logical Analysis	____
6. Memory - Things and Ideas	____
7. Planfulness and Resourcefulness	____
8. Alertness, Cautiousness, and Accuracy	____
9. Concentration, Persistence, and Patience	____
10. Initiative and Incisiveness	____

2.3.3 Scoring Criteria - Quantitative evaluation of these items range from 0 to 4 and are defined in the following manner:

   4   The maintenance action requires a _minimum_ effort on the part of the technician.

3   The maintenance action requires a _below average_ effort
     on the part of the technician.

2   The maintenance action requires an _average_ effort on
     the part of the technician.

1   The maintenance action requires an _above average_ effort
     on the part of the technician.

0   The maintenance action requires a _maximum_ effort on
     the part of the technician.

These criteria will be used in scoring the following speci-
fic divisions of physical, mental, and motor requirements.

ITEM NO. 1   ARM, LEG, AND BACK STRENGTH

Determines the degree of arm, leg, and back strength re-
quired to complete the maintenance action. Refers to any
effort, no matter how minimal. Varying degrees of
strength are required for various maintenance actions as
related to equipment design.

ITEM NO. 2   ENDURANCE AND ENERGY

Determines the degree of endurance and energy required to
complete the maintenance action. Endurance might be referred
to as the physical counterpart of patience, where a
sustained physical effort is required. Energy required to
complete the maintenance action when the task requires
vigourous activity or exertion by the technician is also
assessed. This applies to the necessity of lifting and
carrying heavy assemblies, tools, or parts.

ITEM NO. 3   EYE-HAND COORDINATION, MANUAL DEXTERITY, AND
              NEATNESS

Determines the degree of eye-hand coordination required to
complete the maintenance action. Refers to any act in-
volving the use of the eyes while manipulating the hands to
accomplish the same action. This type of action would be
applicable mostly in testing and measuring activities;
however, it is not inconceivable that this item would also

be applicable in other areas of the maintenance action. Scoring shall be proportional to the degree or the intensity of the requirements of the task.

Determines the degree of manual dexterity required to complete the maintenance action. When the skillful use of the hands is required to accomplish the task, appropriate degrees of necessity shall be established. Those type actions involving manual dexterity would more naturally apply to the repair, assembly, or disassembly of equipments rather than the troubleshooting processes.

Also determines the degree of neatness required by the maintenance action. Applies specifically to the requirement of the actual repair where tidiness is of prime importance to accomplish the task adequately. Since equipment is designed and constructed in accordance with quality control specifications, it is important to consider the care which has to be exercised during a particular repair.

ITEM NO. 4 VISUAL ACUITY

Determines the degree of visual acuity required to complete the maintenance task. When the maintenance action is such that the visual accuracy of the technician is required to accomplish the task, a degree of requirement shall be established. Such actions shall include the need for accurate and precise visual activity in finding indications of trouble, faulty components, or the visual sensitivity sometimes necessary in reading certain oscilloscope presentations.

ITEM NO. 5 LOGICAL ANALYSIS

Determines the degree of logical analysis required to complete the maintenance action. Refers to the need for involved logical analysis or for extensive mental reasoning to determine the origin of the fault or malfunction. If the problem is such that it requires orientation on the logical signal sequence, then this shall also be considered as part of this question.

ITEM NO. 6 <u>MEMORY - THINGS AND IDEAS</u>

Determines the degree to which the maintenance action re-
quires a knowledge of the equipment past history with
reference to component or part failure, tools to be used,
and sequences to be followed (assembly, disassembly, etc.)

Also determines the degree to which the maintenance action
requires a previous knowledge of the equipment. Refers to
the degree that the task requires recall of concepts or
principals of operation, function and operation of circuits
and parts, or electronic theory and maintenance procedures.

ITEM NO. 7 <u>PLANFULNESS AND RESOURCEFULNESS</u>

Determines the degree of planning required to complete
the maintenance action successfully. Refers to the
extent to which the task requires a planned and method-
ological approach to assure rapid diagnosis and repair of
the equipment fault or malfunction.

Also determines the degree of resourcefulness required to
complete the maintenance action. Refers to the capabili-
ties necessary in dealing with a situation or in meeting
difficulties pertaining to the diagnosis and repair of the
equipment. Conditions sometimes exist where certain
needed materials such as tools, test equipment, or tech-
nical publications are not available, although substitution
is possible, by some improvised method, to accomplish the
task adequately.

ITEM NO. 8 <u>ALERTNESS, CAUTIOUSNESS, AND ACCURACY</u>

Alertness is a readiness or promptness in comprehending and
a keen awareness and knowledge of all events or factors
affecting the maintenance action. Cautiousness is the
exercise of forethought so that risks may be avoided or
minimized during the maintenance action. (A surveyance
of all possible consequences before making a decision.)
Accuracy is attained by the exercise of care by showing
close attention to the details of the maintenance task
and cautiousness in avoiding errors. The design require-
ments for these characteristics are to be assessed.

ITEM NO. 9 <u>CONCENTRATION, PERSISTENCE, AND PATIENCE</u>

Concentration is the close mental application or exclusive attention to the maintenance task and the direct focusing of the mind upon one thing to the exclusion of everything else. Persistence refers to maintenance tasks with the implication of being able to carry performance to a success- ful conclusion. Patience is the quiet perserverance, calm- ness in working, and being undisturbed by obstacles, delays, or failures which might occur during the maintenance task.

ITEM NO. 10 <u>INITIATIVE AND INCISIVENESS</u>

Initiative is the energy or aptitude displayed in the initiation of action and the ability or power to introduce a new measure or course of action. Incisiveness is the keenness of mind and acuteness of understanding the task at hand.

3. SUPPORT CHECKLISTS

The support factors, although not directly related to an equipment design, can adversely affect the maintenance capability of an equipment facility. Scoring these fac- tors permits comparisons to be made between equipments operated under various field conditions and development of adjustment factors for predicted and laboratory derived maintainability evaluations. The checklists are as follows:

    a. Checklist E: Scoring Manuals, Technical Orders, and Instructions

    b. Checklist F: Scoring Supply Conditions

    c. Checklist G: Scoring Test Equipment and Tools

    d. Checklist H: Scoring Maintenance Organization

Checklist, E, F, and G are scored for each maintenance task observed. Checklist H relates to factors which change only over a relatively long period of maintenance observation. This checklist is to be scored whenever there is a change in the maintenance organization or

facility. In any event the checklist will be scored at least once each month during the observations as a minimum requirement for the review of these factors. A discussion and presentation of each checklist is presented in the following paragraphs.

3.1 CHECKLIST E - SCORING MANUALS, TECHNICAL ORDERS, AND INSTRUCTIONS

This checklist provides an evaluation of the various technical information that is required for each maintenance task. These requirements will vary depending on the complexity of the maintenance task and the competence of the maintenance technician. The usefulness of the reference . documents is measured by such factors as completeness and clarity of information, method of schematic presentation, etc.

3.1.1 Question Description - Questions 1 thru 4 are concerned with general contents of Technical Orders and instructions as judged for each maintenance task. Such considerations as availability, clarity and completeness are scored. Questions 5 thru 7 are concerned with schematics and other diagrams which are useful in troubleshooting. Question 8 deals with the equipment checkout procedures in respect to their access in the Technical Orders and instruction manuals. Question 9 covers additional maintenance aids provided in handbooks such as flow charts, pictorial illustrations, etc. Question 10 refers to documentation of equipment modifications or maintenance procedures which may have resulted from field studies, factory changes, etc.

3.1.2 <u>Checklist E, Scoring Manuals, Technical Orders, and Instructions</u>

1. <u>Availability of Manuals, Technical Orders and Instructions</u>

    a. All manuals, technical orders, and/or instructions necessary for task completion immediately available... 4

    b. Most, but not all, manuals, technical orders, and/ or instructions necessary for task completion immediately available..............................2

    c. Most manuals, technical orders, and/or instructions necessary for task completion missing....... 1

    d. No manuals, technical orders, and/or instructions necessary for task completion available........... 0

2. <u>Clarity of Manuals, Technical Orders, and/or Instructions</u>

    a. Adequate description of maintenance procedures to be followed are presented in clear, concise manner... 4

    b. Description requires reference to theory of operation to fully comprehend..................... 3

    c. Technical order contains the required information, but much time is consumed in its location or understanding (more than 3 min.)................... 2

    d. Required information is not contained............. 0

3. Accuracy of Technical Orders and/or Instructions

    a. All technical orders and/or instructions needed
       for task accurate (no errors or omissions) and
       completely up-to-date............................ 4

    b. Most technical orders and/or instructions needed
       for task accurate (no errors or omissions) and
       completely up-to-date............................ 2

    c. One or more errors or omissions (or lack of up-
       dating) in technical orders and/or instructions
       needed for task.................................. 0

4. Completeness of Technical Orders and/or Instructions

    a. Required signal characteristics and/or tolerances
       for each test point necessary for task stated..... 4

    b. Most, but not all, required signal characteristics
       and/or tolerances necessary for task stated....... 2

    c. Most, but not all, signal characteristics and/or
       tolerances necessary for task omitted..............1

    d. No signal characteristics and/or tolerances
       necessary for task stated........................ 0

5. **Availability of Schematics and Circuit Diagrams**

    a. All schematics and/or circuit diagrams necessary for task completion immediately available......... 4

    b. Some data on hand, others must be checked out of technical library................................. 3

    c. All must be checked out of technical library...... 2

    d. Some schematics and/or circuit diagrams necessary for task completion missing....................... 1

—

6. **Accuracy of Schematics and/or Circuit Diagrams**

    a. All schematics and/or circuit diagrams necessary for task completion accurate (no errors) and completely up-to-date............................. 4

    b. One or more errors (or lacking up-dating) in schematics and/or circuit diagrams needed for task.... 0

—

7. **Completeness of Schematics and/or Circuit Diagrams**

    a. Required signal characteristics and/or tolerances for each test point necessary for task stated..... 4

    b. Most, but not all, required signal characteristics and/or tolerances necessary for task stated....... 2

    c. Most, but not all, signal characteristics and/or tolerances necessary for task omitted............. 1

    d. No signal characteristics and/or tolerances necessary for task stated............................... 0

—

8. <u>Presentation</u>

   a. Checkout procedures and associated minimum per-
   formance standards for the equipment are presented
   clearly in a single section of the handbook....... 4

   b. Most of the required check out minimum performance
   information has been consolidated but not more
   than two sections must be consulted................ 2

   c. More than two sections of the handbook must be con-
   sulted to determine proper operating parameters....0

                                                        ——————

9. <u>Maintenance Aids</u>

   a. Technical data provides simplified data flow
   diagnosing and pictorial representation of equip-
   ment to assist in the maintenance task........... 4

   b. Some maintenance aids are provided............... 2

   c. Little or no supplementary information is pro-
   vided... 0

                                                        ——————

10. <u>Up-Dating</u>

   a. All modification data is available to technician.. 4

   b. Data on hand but not readily available........... 2

   c. Information has not been secured.................. 0

                                                        ——————

3.1.3 Scoring Criteria

ITEM NO. 1 **AVAILABILITY OF MANUALS, TECHNICAL ORDERS, AND INSTRUCTIONS**

Determine if the manuals, technical orders and instructions required to complete the task are procured immediately or because of sign-out procedure or physical location, some time was consumed acquiring needed material. Although similar to Item No. 5, this question pertains specifically to the availability of printed technical matter and not schematics and diagrams.

Scoring Criteria

a. To be scored when required publications are at the area of the malfunction and no appreciable time is spent locating needed material.

b. To be scored when the majority of required manuals, technical orders, and instructions required to complete the maintenance action are available.

c. To be scored when the majority of required technical material is not available to maintenance personnel.

d. To be scored when no technical information required to complete the maintenance action is available.

ITEM NO. 2 **CLARITY OF MANUALS, TECHNICAL ORDERS, AND INSTRUCTIONS**

Determines if maintenance procedures refer to the step-by-step instructions to be followed during tuning, testing, mechanical assembly and disassembly, etc. Such procedures, when required to complete the maintenance task are to be evaluated according to presentation and clarity.

Scoring Criteria

a. To be scored when required maintenance procedures are presented in a manner whereby they are easily understood and followed. This is indicative of a best maintenance

condition.

b. To be scored when it is necessary for maintenance personnel to cross-reference other technical material in order to comprehend fully or follow the maintenance procedure.

c. To be scored when the needed manual or technical order does not afford adequate internal reference or when an excess of three minutes is expended locating desired chapter, paragraph, etc.

d. To be scored when required procedures are not contained in the available manuals, technical orders or instructions. This indicates that a least maintainable condition exists.

ITEM NO. 3 ACCURACY OF TECHNICAL ORDERS AND INSTRUCTIONS

Determines if the technical orders and instructions needed to complete the maintenance task are accurate and up-to-date. If such technical information contains errors or is out-dated, considerable time could be expended deciphering mistakes, following erroneous procedures, troubleshooting etc.

Scoring Criteria

a. To be scored when required technical information is accurate in descriptions of equipment operation, theory, maintenance procedures and contains all applicable revisions.

b. To be scored when the majority of technical data needed for task is correct and up-to-date.

c. To be scored when technical orders and instructions required for task completion contains one or more inaccuracies and/or lack of up-dating.

ITEM NO. 4 COMPLETENESS OF TECHNICAL ORDERS AND INSTRUCTIONS

Determines if test points are sufficiently labelled

according to signal characteristics, tolerances, amplitude
and polarity within the technical manual. Such information
is of primary importance during diagnosis and trouble-
shooting of the fault or malfunction. During testing,
maintenance personnel should know precisely what is to be
read or indicated at a particular test point. If this
information is not supplied, possible trouble areas may
be overlooked, thereby increasing maintenance time.

Scoring Criteria

a. To be scored when all test points required during
the maintenance task are referenced in technical orders
or instructions and include their signal characteristics
(amplitude, pulse duration, and tolerance).

b. To be scored when the majority of required test points
are referenced in technical orders or instructions and
include their signal characteristics.

c. To be scored when the majority of required test points
are not referenced in technical orders or instructions,
but signal characteristics are available.

d. To be scored when no signal characteristics are stated
in technical orders or instructions at test points re-
quired for the maintenance task.

ITEM NO. 5 AVAILABILITY OF SCHEMATICS AND CIRCUIT DIAGRAMS

Determines if all schcematics and circuit diagrams required
to complete the maintenance task are procured immediately
or because of physical location or sign out procedure,
excessive time was consumed acquiring needed material.
Although similar to No. 1 this item specifically relates
to schematics, logic diagrams, wiring diagrams, etc.

Scoring Criteria

a. To be scored when schematics and circuit diagrams
necessary for task completion are immediately available
at the area of the malfunction and no appreciable time is
spent procuring such information.

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b. To be scored when the majority of needed schematics
and circuit diagrams are immediately available but other
material must be procured at another location (Technical
Order library, files, etc.).

c. To apply when all required schematics and circuit dia-
grams must be procured at another location (library, files,
etc.).

d. Applicable when some of the required schematics and cir-
cuit diagrams are not available at any location within the
using site or base.

ITEM NO. 6 <u>ACCURACY OF SCHEMATICS AND CIRCUIT DIAGRAMS</u>

Determines if the schematics and circuit diagrams required
to complete the maintenance task are accurate and up-to-
date. If such information contains errors, considerable
time could be expended tracing circuits, troubleshooting
and isolating the fault or malfunction.

<u>Scoring Criteria</u>

a. Applies when all schematics and circuit diagrams used
during the maintenance task are accurate in reference to
present system design and revised to include changes.

b. Applies when one or more errors are evident in sche-
matics or circuit diagrams used during the maintenance
task or latest revised prints are not available.

ITEM NO. 7 <u>COMPLETENESS OF SCHEMATICS AND CIRCUIT DIAGRAMS</u>

Determines if test points are adequately labelled according
to signal characteristics, tolerance, amplitude and polari-
ty on schematics and circuit diagrams. Such information is
of primary importance during troubleshooting of the fault or
malfunction. During testing, maintenance personnel need to
know precisely what should be read or indicated at a par-
ticular test point. If this information is not supplied,
possible trouble areas may be overlooked, thereby increas-
ing maintenance time.

Scoring Criteria

a. To be scored when all test points required for task completion are referenced on schematics and include signal characteristics and tolerances (amplitude, pulse duration, polarity, etc.).

b. To be scored when the majority of required test points are referenced in schematics and include their signal characteristics.

c. To be scored when the majority of required test points are not referenced in schematics, but signal characteristics are available.

d. To be scored when no signal characteristics are stated in schematics at test points required for the maintenance action.

ITEM NO. 8 PRESENTATION

Determines if check out procedures and operating instructions are clearly presented, understood, and available in one section of the technical order or manual.

Scoring Criteria

a. To be scored when check out procedures and operating standards are accurate with respect to system performance and presented clearly in one section of the handbook.

b. To be scored when not more than two sections of a Technical Order or manual must be consulted in referencing check out procedures or operating standards.

c. To be scored when more than two sections of the Technical Order or manual must be consulted.

ITEM NO. 9 MAINTENANCE AIDS

Determines if technical publications provide signal path information in simple block or flow diagram making it possible for inexperienced personnel to troubleshoot and

repair malfunctions.

Scoring Criteria

a. To be scored when such simplified signal trace diagrams pertaining to the maintenance task are included in Technical Orders or instructions.

b. To be scored when some such aids applicable to the maintenance tasks are available.

c. To be scored if little or no such simplified information pertaining to the task is available.

ITEM NO. 10 UP-DATING

Determines if all equipment modification data pertaining to the task at hand is available to maintenance personnel.

Scoring Criteria

a. To be scored when all modification data related to the task is immediately available to maintenance personnel.

b. To be scored when modification data pertaining to the task is not immediately available but must be secured from another location, signed-out, etc.

c. To be scored when no modification data pertaining to the task is available.

3.2 CHECKLIST F - SCORING SUPPLY CONDITIONS

This checklist concerns the availability of parts, modules, assemblies, etc. which are needed to complete the maintenance task. Logistics policies normally will be established for the equipment prior to field operational acceptance. Spares provisioning may be established at the part, module, assembly or other levels. In many cases a combination of one or more may be established to provide support for the equipment. This support is considered to be an important factor in the maintenance of electronic equipment since its operational status is a

function of the availability of required spares, supply
procedures, and procurement reference data.

3.2.1 <u>Question Description</u> - Questions 1 thru 4 relate
to the amount of time required to obtain needed replace-
ments to complete a maintenance task. Question 5 pertains
to material which may be essential in performance of the
maintenance task. Cleaning fluid, cloth, wire, etc. are
typical examples of material which should be immediately
available to the technician. Question 6 and 7 refer to
the process of ordering replacements include necessary
paper work to initiate supply action through appropriate
supply channels. Question 8 pertains to the location
where replacements are stocked. In some instances normal
supply channels will include authorized local purchases
which do not involve government supply channels. Ques-
tion 9 concerns tools to accomplish a particular task.
For example the authorized complement of tools for the
technicians kit may be incomplete due to breakage, lack
of original supply, etc. Question 10 covers coordination
the technician requires with supply personnel to obtain
necessary material to complete the task.

3.2.2 <u>Checklist F, Scoring Supply Conditions</u>

1. <u>Accessability</u>

   a. Parts were immediately available (0-5 minutes).... 4

   b. Some time expended in obtaining parts (5-30
      minutes)... 2

   c. Excessive time consumed to secure part due to red
      tape, waiting time, etc............................ 1

   d. Part not available................................. 0

2. <u>Acceptability</u>

   a. Part is entirely suitable for intended purpose.
Consider electrical, mechanical, reliability, and
quality control factors............................. 4

   b. Parts do not meet or exceed original character-
istics.. 0

                                                        ————

3. <u>Relative Location</u>

   a. Stock room is adjacent to or part of working
area.. 4

   b. Some delay experienced due to physical location.... 2

   c. Much delay encountered.............................. 0

                                                        ————

4. <u>Packing</u>

   a. Time spent in unpackaging new part, or repacking
old part if require, is of little significance
(less than 2 minutes).............................. 4

   b. Some delay experienced due to this requirement
(2-10 minutes)..................................... 2

   c. Much time consumed (over 10 minutes)............... 0

                                                        ————

5. **Auxiliary Materials**

   a. All auxiliary materials (cleaning fluids, solder, wire, etc.) immediately on hand...................... 4

   b. Some delay experienced in securing required items.. 2

   c. Much delay encountered............................. 0

6. **Parts Identification**

   a. Identification information (stock number) for required part was quickly obtained through use of parts lists, cross reference or local identification lists (less than 1 minute)......................... 4

   b. Some delay was experienced due to lack of proper data (1-3 min.)..................................... 2

   c. Considerable delay was experienced (over 3 minutes).. 0

7. **Supply Forms**

   a. Little time consumed in completing supply forms (less than 1 minute)............................... 4

   b. Some time expended (1-3 minutes)

   c. Considerable time used (more than 3 minutes)....... 0

8. Local Bench

   a. Part was immediately available from local bench
      stock... 4

   b. Normal supply channels used to secure parts........ 2

   c. Part secured through cannibalization............... 0

   _____

9. Tools

   a. All tools immediately on hand in the working area.. 4

   b. Standard tools are kept in working area but special
      tools are stored in supply......................... 2

   c. All tools must be checked out of supply............ 0

   _____

10. Supply Coordination

   a. Supply personnel were not contacted during the
      maintenance procedure.............................. 4

   b. Limited contact required............................ 2

   c. Considerable coordination with supply required..... 0

   _____

3.2.3 Scoring Criteria

ITEM NO. 1 ACCESSABILITY

Determines the availability of parts needed to complete
the maintenance action. When the equipment fault or mal-
function has been isolated, successive procedure usually
consist of repair and check out. Since supply conditions
are related to the repair or replacement of the defective

component or part, the task can only be accomplished when needed parts are available to maintenance personnel. The effectiveness of maintenance will therefore be directly proportional to the availability or time to procure needed parts.

Scoring Criteria

a. To be scored when needed parts are procured within 5 minutes.

b. To be scored when needed parts are procured within 30 minutes.

c. To be scored when an excessive amount of time (over 30 minutes) is expended securing needed parts.

d. Applicable when needed replacements are not available at unit or base supply levels.

ITEM No. 2 ACCEPTABILITY

Determines if the replacement part or component is suitable to the particular circuit configuration. Refers to such parts as resistors, capacitors, coils, etc. which require replacement. Such items should be identical to the parts removed unless the maintenance action involves a modification where a change of value is authorized. In cases where a direct replacement is not available and a substitute is used, having different characteristics, a less maintainable condition would exist due to the supply deficiency.

Scoring Criteria

a. To be scored when the replacement has the same characteristics as that of the part removed unless a modification is authorized or required.

b. To be scored when the replacement does not meet or exceeds required characteristics (value, tolerance, wattage rating, working volts, etc).

ITEM No. 3 RELATIVE LOCATION

Determines if an appreciable amount of time is spent
securing needed replacements due to the physical location
of the supply facility. When it is necessary to replace
a component or part during the maintenance action, this
item will determine if the supply facility is strategically
located with respect to the equipment area.

Scoring Criteria

a. To be scored when the replacement part is available at
the area of the malfunction or directly adjacent thereto.

b. To be scored when the task is delayed due to the phy-
sical location of the supply facility.

c. To be scored when an extended period of time is re-
quired to secure replacements due to the physical location
of the supply facility.

ITEM No. 4 PACKAGING

Determines the delay applicable to unpacking or packing
parts in time increments from 2 to 10 minutes. Refers
to uncrating or unpackaging of parts and components re-
quired to complete the maintenance action. When it be-
comes necessary to package or unpackage the part or com-
ponent during the task, the extent to which a box or crate
must be assembled or disassembled will directly affect the
total maintenance time.

Scoring Criteria

a. To be scored when less than 2 minutes is expended un-
packing or packing parts.

b. To be scored when a delay (2 to 10 minutes) is experi-
enced packing or unpacking parts.

c. To be scored when an excess of 10 minutes is spent
packing or unpacking parts.

ITEM No. 5 AUXILIARY MATERIALS

Determines if auxiliary materials required for the task
are immediately available. The maintenance action will
often require the use of supplementary materials other
than tools and test equipment. An example of such mate-
rials would be cleaning fluid, solder, flux, cloth, rags,
etc. These materials could conceivable be as important
to the task as replacement parts, tools or test equip-
ment, therefore their availability must be evaluated.

Scoring Criteria

a. To be scored when all auxiliary materials required
for the task are immediately available at the area of
the malfunction.

b. To be scored when a delay is encountered procuring
needed auxiliary materials.

c. To be scored when an appreciable delay is encountered
procuring needed materials.

ITEM No. 6 PARTS IDENTIFICATION

Determines if supply procedures are set up in such a manner
as to expedite the location of needed replacements. This
takes into consideration supply procedures and red tape
which are often complicated and time consuming. When parts
or components are required to complete the maintenance ac-
tion and these complicated procedures must be followed in
order to procure needed materials, the overall maintenance
time will be affected. An example of such procedures might
be shelf or bin labels, stock numbers, cross reference
files, locator cards, etc.

Scoring Criteria

a. To be scored when less than one minute is spent loca-
ting replacement via parts lists, supply locator files, etc.

b. To be scored when a delay not in excess of 3 minutes is
encountered locating replacement via parts lists, etc.

c.   To be scored when a delay in excess of 3 minutes is experienced locating replacements via parts lists, etc.

ITEM No. 7   SUPPLY FORMS

Determines if the completion of supply forms, in any way, delays the maintenance task.   When replacement parts must be procured from the supply facility, it will be determined if the completion of such forms as request slips and up-dating stock cards delayed the maintenance action.

Scoring Criteria

a.   To be scored when less than 1 minute is spent completing request forms, up-dating stock cards, etc.

b.   To be scored when not more than 3 minutes is expended completing forms.

c.   To be scored when an excess of 3 minutes is expended completing supply forms.

ITEM No. 8   LOCAL BENCH STOCK

Determines the availability of needed replacements from local bench stock.   Often the repair of an equipment fault or malfunction can be completed with parts secured from local bench stock.   Such situations would tend to expedite the repair if bench supplies are in close proximity to the equipment and no formal procedure is required.

Scoring Criteria

a.   To be scored when replacement is immediately secured from local bench stock at the area of the malfunction.

b.   To be scored when replacement must be secured from unit or base supply via normal supply channels.

c.   To be scored when replacement must be secured from a redundant system or from a unit using a similar part.

ITEM No. 9 <u>TOOLS</u>

Determines if all tools required for the task are available at the area of the malfunction or procedure required that they be stored at the supply facility and signed out when needed. Equally important to the repair of electronic equipment are proper tools which should be available immediately. It is conceivable that the equipment repair would be delayed indefinitely due to lack of needed tools. On the other hand improvised methods of disassembly and parts removal might be attempted so that the end result could be detrimental to the equipment.

<u>Scoring Criteria</u>

a. To be scored when all tools required for task are immediately available at the area of the malfunction.

b. To be scored when special tools required for the task must be procured at the supply facility.

c. To be scored when all tools required for task must be procured at the supply facility.

ITEM No. 10 <u>SUPPLY COORDINATION</u>

Determines whether or not coordination with supply personnel is required, and if so, to what extent.

<u>Scoring Criteria</u>

a. To be scored when the maintenance action does not require coordination with supply personnel.

b. To be scored when some contact with supply personnel is required during the maintenance action.

c. To be scored when considerable coordination with supply personnel is required to complete the maintenance action.

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3.3 CHECKLIST G - SCORING TEST EQUIPMENT AND TOOLS

This checklist scores factors related to the tools and test equipment required to accomplish the maintenance task. The availability and operating condition of these items determines in part the capability of the maintenance technician to accomplish the task successfully in a reasonable period of time. Erroneous test equipment presentations and faulty tools result in delays in completing the task. If specific test equipment is required but is not available, or does not operate properly, successful completion of the task will be delayed because of the necessity of the technician to substitute and improvise.

3.3.1 Question Description - Questions 1 thru 4 relate to test equipment availability and capability for operation. Both bench type and portable test equipment are taken into consideration in scoring. Each is considered in respect to ancillary items and calibration status. If test equipment requires considerable setup time and accessories, accomplishment of the task will be compromised accordingly. Question 5 and 6 is concerned with the status of both standard and special tools required for the task. In checklist F, supply conditions associated with tools are considered (question 9). Question 5 and 6 is to determine if the proper tool for the task is available and is in satisfactory condition. Question 7 refers to the design capability of the test equipment. If a multimeter is used where a precision voltmeter is required, it would be necessary for the technician to interpret on a particular voltage range, for example, to make adjustments and obtain a reading. Question 8 scores the availability of instructions for the test equipment. Question 9 determines the portability of the test equipment. Questions 10 thru 13 relate to the design features of the test equipment which permits manipulation as well as flexibility for accomplishment of the task. Equipments which provide presentations directly in required measurement, as for example, power rather than db, or can be set for a number of measurements, such as frequency without recalibration are desireable features.

3.3.2 Checklist G, Scoring Test Equipment and Tools

1. **Availability (Bench Type)**

   a. All required test equipment and accessories
      needed for task accomplishment available to
      accomplish task.................................. 4

   b. Substitute equipment was used in lieu of specified
      equipment for some tests (less than two)......... 2

   c. Insufficient equipment available................. 0

2. **Availability (Portable Type)**

   a. All required test equipment and accessories
      needed for task accomplishment available to
      accomplish task.................................. 4

   b. Substitute equipment was used in lieu of specified
      equipment for some tests (less than two)......... 2

   c. Insufficient equipment available................. 0

3. **Operating Condition**

   a. All test equipment is in good operating condition
      and is within its calibrated period............. 4

   b. Most test equipment is in good operating condition
      and is within its calibrated period............. 3

   c. Test equipment is operating but calibrated
      accuracy is in doubt............................. 2

   d. Some test equipment needed for task accomplish-
      ment is incapable of performing assigned task.... 0

4. <u>Preparation</u>

    a. Test equipment required very little preliminary
set-up (less than 3 minutes)...................... 4

    b. Test equipment required moderate preliminary
set-up (3-10 min.)................................ 2

    c. Extensive preparation time is used (over 10 min.) 0

5. <u>Tools</u> (Standard)

    a. All tools required to perform maintenance are
immediately available and in good condition...... 4

    b. Most tools required to perform maintenance are
immediately available and in good condition...... 3

    c. Use of substitute tools required, due to lack
of proper items................................... 2

    d. Insufficient tools available to perform task..... 0

6. <u>Tools</u> (Special Type)

    a. All tools required to perform maintenance are
immediately available and in good condition...... 4

    b. All but one tool required to perform main-
tenance are immediately available and in
good condition.................................... 2

    c. Use of substitute tools required, due to
lack of proper items.............................. 0

7. <u>Test Equipment Capabilities</u>

    a. Test equipment is capable of giving all
       information needed to perform task.............. 4

    b. Test equipment is capable of giving most
       required information to perform task............. 2

    c. Incapable.. 0

8. <u>Manuals</u>

    a. Handbooks and/or instructions are available
       for test equipment used.......................... 4

    b. Most handbooks and/or instructions are avail-
       able for test equipment used..................... 2

    c. No handbooks and/or instructions are available
       for test equipment used.......................... 0

9. <u>Handling</u>

    a. All test equipment required to be portable
       weighs less than 35 pounds or is provided
       with cart.. 4

    b. Most test equipment required to be portable
       weighs less than 35 pounds or is provided
       with cart.. 4

    c. Test equipment does not meet these requirements.. 0

10. <u>Calibration</u>

    a. Calibration controls on test equipment are
       physically separated from those used in
       operation.. 4

    b. Controls are separated on most of the test
       equipment.. 2

    c. Controls are not separated..................... 0

11. <u>Presentations</u>

    a. Test equipment indications are easily read by
       technician applying test leads to circuit
       under test....................................... 4

    b. Some difficulty experienced..................... 2

    c. Two technicians are required to perform test..... 0

12. <u>Conversion Factor</u>

    a. Test equipment provides information in units
       directly applicable to check being made.......... 4

    b. Conversion required but calibration or con-
       version charts do not impose a serious handi-
       cap.. 2

    c. Considerable time consumed in converting test
       equipment data to usable form (More than one
       minute).. 0

13. Automatic Qualities

    a.   Test equipment is automatic requiring no operational adjustments while in use............ 4

    b.   Some adjustments must be made to accomplish check...................................... 2

    c.   Extensive manipulations are required............ 0

3.3.3 Scoring Criteria

ITEM No. 1 AVAILABILITY (Bench Type)

Encompasses all bench type test equipment which is classified as bulky in nature, requiring more than one man to manipulate or which cannot be handled without a great deal of effort. It would also include all test equipment, standard or specialized, that is normally carried on a cart. The availability of this equipment is to mean that it is easily accessible to the immediate or surrounding work area and is operational.

Scoring Criteria

a. To be scored if all bench or rack mounted test equipment, their leads, connectors, and other accessories are available to accomplish the task at hand.

b. To be scored if it is necessary to substitute bench or rack mounted test equipment in one or two instances because of the unavailability of the specific type required.

c. To be scored if a situation exists where a needed test set is not available and cannot be substituted.

ITEM No. 2 AVAILABILITY (Portable Type)

Encompasses all test equipment that is portable in nature, by size, weight, and utilization. Typical examples of these would be multitesters, volt-ohm-current meters,

bridge testers, continuity type checkers, etc. A general
rule for distinguishing between portable and bench type is
to classify portable as that type test equipment that is
normally carried by one person without being burdened by
weight or size. The availability of this equipment is to
mean that it is located in the immediate or surrounding
work area and is operational.

Scoring Criteria

a. To be scored if all test equipment of portable type,
their leads, connectors, and other accessories are immedi-
ately available to accomplish the task at hand.

b. To be scored if it is necessary to substitute test
equipment in one or two instances because of the unavail-
ability of the specific types required.

c. To be scored if a situation exists where more than
two substitutions are necessary or where specific portable
test equipment is not available and cannot be substituted.

ITEM No. 3   OPERATING CONDITION

Determines if the operating condition of the test equip-
ment is adequate to complete the requirements of the task.
If needed test sets are not calibrated or otherwise not
operating properly, errors in failure diagnosis could re-
sult, thereby extending the maintenance action.

Scoring Criteria

a. To be scored if all test equipment, their leads, con-
nectors, and other accessories are in good operating con-
dition and are adequately calibrated to accomplish the
task.

b. To be scored if most, but not all of the required test
equipment is in sufficient operating condition and adequate-
ly calibrated to meet the requirements of the task.

c. To be scored if the test equipment necessary for com-
pletion of the task is operating sufficiently, however it

is assumed that the calibration is inaccurate.

d. To be scored if all of the test equipments required for task accomplishment is incapable of performing the task at hand.

ITEM NO. 4   PREPARATION

Encompasses the total time required to set up all test equipment for the accomplishment of any single maintenance task. This shall include placing of equipment, initial connection of leads and all preliminary adjustments required before proceeding with the actual testing of the system.

Scoring Criteria

a. To be scored if the test equipment for the entire task requires a set up time of less than 3 minutes for the required tests.

b. To be scored if the total time required to set up for all testing exceeds 3 minutes, but does not require more than 10 minutes.

c. To be scored if the total time required to set up all test equipment requires more than 10 minutes. This would be an indication of a least maintainable condition.

ITEM NO. 5   TOOLS (Standard)

Includes those tools that are considered a normal part of the technicians tool box. Some examples of these would be; a soldering iron, spin-tights, long nose pliers, diagonals, or Phillips screw drivers. In contrast, special tools would be considered those which are used on one particular equipment only.

Scoring Criteria

a. To be scored if all standard type tools necessary to perform the task at hand are available and are in useable condition.

b. To be scored if the majority of standard tools necessary for task completion are available and in a useable condition.

c. To be scored if the unavailability or condition of the standard tools requires substitutes to complete the maintenance action.

d. To be scored if there are insufficient standard type tools and no substitutes are available to accomplish the task adequately.

ITEM NO. 6 TOOLS (Special Type)

Includes those tools which are designed for use on specific equipment or special equipment assemblies. Tools commonly found in the standard tool box would not be included in this category.

Scoring Criteria

a. To be scored if all special type tools necessary to perform the task at hand are available and are in useable condition.

b. To be scored if all but one special type tool needed to complete the task is available and in useable condition.

c. To be scored when substitute tools are required other than those designed for the job or when very few of the prescribed tools are available.

ITEM NO. 7 TEST EQUIPMENT CAPABILITIES

Encompasses the ability of the test equipment to perform the functions of its design and also takes into consideration the adequacy of the test equipment design to perform the particular requirements necessary to complete the maintenance task at hand.

Scoring Criteria

a. To be scored if the prescribed test equipment required

to perform the task is operational and capable of giving all the information necessary to complete the task adequately.

b. To be scored if the prescribed test equipment required to perform the task is operational and capable of giving some of the information necessary to complete the task.

c. To be scored when all the prescribed test equipment, although operational, is incapable of giving the required information.

ITEM NO. 8 MANUALS

Encompasses the operating instructions and manuals which normally accompany the test equipment. The use of such material often becomes necessary to perform certain unfamiliar test equipment procedures or to familiarize the technician with the capabilities of a new equipment.

Scoring Criteria

a. To be scored if the performance of the task requires use of a test equipment handbook or instructions and all were available.

b. To be scored if the test equipment handbook or instructions are only partially adequate to meet the requirements of the task.

c. To be scored if there are no handbooks or instructions available to aid in the performance of the task.

ITEM NO. 9 HANDLING

Determines the ease of test equipment handling for completion of the maintenance task at hand. This pertains to the necessity of carrying the testing devices to various test locations throughout the equipment area.

<u>Scoring Criteria</u>

a. To be scored when all test equipment used to accomplish the task, requiring portability within the immediate equipment area, is either under 35 pounds or is conveyed by a cart or similar device.

b. To be scored, when most of the test equipment requiring portability is either under 35 pounds or is conveyed on a cart or similar device.

c. To be scored if very few (or none) of the test equipment requiring portability are under 35 pounds or are not conveyed by a cart of similar device.

ITEM NO. 10 <u>CALIBRATION</u>

Encompasses the calibration qualities and qualifications of the test equipment necessary to accomplish the maintenance task adequately. This is to include the required calibration and operating controls with relation to ability to function independently.

<u>Scoring Criteria</u>

a. To be scored if the performance of the task requires test equipment that can be calibrated and the calibration controls are independent of the operating controls.

b. To be scored if the test equipment can be calibrated and the controls are independent of each other on most of the required equipments.

c. To be scored when calibration controls are gauged or dependent upon the operating controls, creating a more lengthy testing procedure.

ITEM NO. 11 <u>PRESENTATIONS</u>

Encompasses such test equipment as oscilloscopes, conventional volt-ohm-current meters, and digital type indicators. This question considers the degree of difficulty in reading the visual presentations associated with

any type test equipment. The factors in determining the
adequacy of this aspect applies to whether the indicator
face is too small and therefore, not clearly presented for
reading at distances or whether too many or very sensitive
adjustments require more than one man to make the tests.

Scoring Criteria

a. To be scored if the test equipment required to complete
the maintenance task has clear presentations which can
easily be read by the test personnel.

b. To be scored if some difficulty is encountered in
observing the presentations.

c. To be scored if it is necessary for a second person
to assist the technician in reading the presentations.

ITEM NO. 12 CONVERSION FACTOR

Determines if the adequacy of the conversion scales on the
test equipment is compatible with the equipment under test.
Also considers the necessity of readjusting or recalibrating
test equipment when changing to another scale. The diffi-
culty in expediting these changes in test equipment
effectively increases the time to complete the maintenance
action.

Scoring Criteria

a. To be scored if the test equipment necessary to accom-
plish the task requires no scale conversion other than
that which can be read directly from the face of the unit.

b. To be scored if the test equipment necessary to accom-
plish the task requires approximately one (1) minute to
convert scales through the use of charts, adjustments to
the equipment, or by mental calculations.

c. To be scored if scale conversion requires more than
one (1) minute whether done by using charts, adjustments,
or by mental calculations.

ITEM NO. 13 AUTOMATIC QUALITIES

Encompasses the automatic qualities designed into the test
equipment which eliminates need for operational adjustments
to make the proper test. This shall also cover calibration
aspects as described in Item No. 12.

Scoring Criteria

a. To be scored if the test equipment required to accomplish
the task at hand is such that no operational adjustments
are necessary to make the proper test.

b. To be scored if some operational adjustments become
necessary to make the proper tests.

c. To be scored if extensive test equipment manipulations
are found to be necessary, becoming time consuming and re-
quiring much effort.

3.4 CHECKLIST H - SCORING MAINTENANCE ORGANIZATION AND FACILITIES STATUS

Checklist H is a general questionnaire which scores various
aspects of the maintenance organization and facilities as
related to the particular equipment. Facilities refer to
such associated items as equipment housing, electrical
power, and test benches and equipment. Factors that are
covered by this checklist tend to remain relatively con-
stant over several maintenance observations. Changes in
such areas as maintenance complement, experience level,
etc. can be expected to occur during the period of ob-
servation. To insure that the checklist is continually
updated, it is required that the checklist be scored when-
ever a change occurs which affects the checklist scoring
and at least once every month during the period of ob-
servation. In general completion of the questions will
require consultation with the supervisory personnel of the
organization; e.g., communications and electronics officer,
maintenance NCOIC, etc.

accomplishment of maintenance tasks. It has been observed
in field studies that poor planning and installation
resulted in unsatisfactory maintenance conditions. For
example, power requirements for the equipment may be
insufficient resulting in equipment failures. Cables may
be routed in a manner so that cor.siderable time is re-
quired to gain access to the equipment and effect a
repair.

3.4.1.6 Environmental Conditions - Questions 19 and 20
pertain to the protection of the equipment from moisture,
heat, dust, etc. Military requirements often necessitate
the use of equipment in climates unfavorable to equipment
operation. Unless proper precaution is taken, maintenance
requirements increase under these circumstances. For
example, antennas which are susceptible to wind loading
require protective covering in regions where high winds
are normally experienced.

3.4.1.7 Working Conditions - Questions 20 thru 23 relate
to working environment of the maintenance personnel. The
need to perform hazardous and difficult tasks are part of
the equipment maintenance may adversely affect the time
required to complete the task. Proper working areas are
particularly important where heat and cold are a paramount
problem. For example, work performed in an overheated
maintenance area can be both a physical and psychological
detriment to the maintenance men.

3.4.1.8 Tools and Equipment Status - Question 24 refers to
the availability of test equipment and tools authorized by
appropriate Air Force regulations and documents. Check-
list G considers these items in respect to their availa-
bility to the technician in the accomplishment of a
particular task. Question 24 is to determine if the main-
tenance organization initiated action to obtain required
test equipment and tools as a prerequisite in achieving
operational status for the equipment. Tools and test
equipment, like electronic parts, oil, grease, etc. must
be ordered with sufficient lead time to assure their
availability when needed.

3.4.2 Checklist H, Scoring Maintenance Organization and Facilities Status

SUPERVISORY LEVEL (Enlisted Personnel)

1. Experience

    a. Supervisor has more than (8) eight years experience in military electronics and procedures............. 4

    b. Supervisor has (5-8) five to eight years experience in military electronics and procedures............. 2

    c. Supervisor has less than (4) four years experience in military electronics and procedures............ 0

PERSONNEL COMPLEMENT

2. Manning

    a. The maintenance section has a full complement of personnel in each skill level as is prescribed in the manning document................................ 4

    b. The maintenance section is lacking in apprentice personnel.. 3

    c. The maintenance section is lacking in specialist personnel.. 2

    d. The maintenance section is lacking in supervisory personnel.. 1

    e. Combination of B and C or B and D.................. 1

    f. Combination of C and D or B, C, D.................. 0

3. Number of Personnel Constituting a Maintenance Team

    a. Adequate in numbers for completion of both major and
        minor tasks..................................... 4

    b. Adequate for minor maintenance tasks............... 2

    c. Inadequate.. 0

    ____

ORGANIZATION AND PROCEDURE

4. Maintenance Duty Schedule

    a. 24 hour operation utilizing a three crew, eight hour
        shift system with both specialists and supervisor on
        each crew...................................... 4

    b. 24 hour operation utilizing a three crew, eight hour
        shift system with specialists on each crew and
        supervisors working straight days.................. 2

    c. 24 hour operation utilizing a three crew, eight hour
        shift system with specialists and supervisors working
        straight days.................................... 0

    ____

5. <u>Organizational Set-Up</u>

    a. Unit operating procedures, maintenance procedures, and duty responsibilities are adequate and fully understood by maintenance personnel................ 4

    b. Unit operating procedures, maintenance procedures, and duty responsibilities are not fully understood by maintenance personnel.......................... 2

    c. Unit operating procedures and/or maintenance procedures inadequate............................... 1

    d. Combination of B and C............................. 0

6. <u>Conflicting Duties</u>

    a. Outside obligations (other than maintenance duties) do not interfere either directly or indirectly with the fulfillment of the maintenance task............ 4

    b. Outside obligations interfere indirectly with the maintenance task...................................... 2

    c. Outside obligations interfere directly with the maintenance task.................................... 0

7. <u>Inspection</u>

    a. Corrected malfunction is not reviewed by inspection personnel.. 4

    b. Approval by inspection must be accomplished before task is considered complete........................ 0

PREVENTIVE MAINTENANCE

8. <u>Schedules</u>

    a. Preventive maintenance schedules are current and easily understood by maintenance personnel....... 4

    b. Preventive maintenance schedules are not easily understood by maintenance personnel.............. 2

    c. Preventive maintenance schedules are not up-to-date...................................... 1

    d. Preventive maintenance schedules are not readily available....................................... 0

---

9. <u>Procedures</u>

    a. Procedures are in accordance with published AF instructions...................................... 4

    b. Some unauthorized modifications have been made... 2

    c. No definite program exists....................... 0

---

10. <u>Procedures - Minor</u>

    a. Preventive maintenance procedures are adequate, uncomplicated, do not interfere with operation, and are performed on schedule.................... 4

    b. Preventive maintenance procedures meet 3 of the above criteria................................. 3

    c. Preventive maintenance procedures meet 2 of the above criteria................................. 2

    d. Preventive maintenance procedures meet 1 of the above criteria................................. 1

    e. Some preventive maintenance procedures cannot be performed.. 0

11. <u>Procedures - Major</u>

    a. Preventive maintenance are adequate, uncomplicated, do not interfere with operation, and are performed on schedule...................................... 4

    b. Preventive maintenance procedures meet 3 of the above criteria................................. 3

    c. Preventive maintenance procedures meet 2 of the above criteria................................. 2

    d. Preventive maintenance procedures meet 1 of the above criteria................................. 1

    e. Some preventive maintenance procedures cannot be performed.. 0

12. <u>Logs</u>

    a.   Preventive maintenance logs are complete and up-to-date.. 4

    b.   Preventive maintenance logs are not up-to-date... 3

    c.   Preventive maintenance logs are not complete..... 2

TEST AND REPAIR

13. <u>Facilities</u> (Non-Portable)

    a.   Test facilities adequate (i.e., well lighted, sufficient power source, adequate work bench provided)....................................... 4

    b.   Test facilities inadequate with respect to one of the above requirements........................ 2

    c.   Inadequate....................................... 0

---

14. <u>Facilities</u> (Portable)

    a.   Test facilities in close proximity to the operating area.................................... 4

    b.   Some delay is experienced due to physical location of test facilities........................... 2

    c.   Much delay experience............................ 0

---

15. <u>Area</u>

    a. Sufficient space, test equipment-tools, and
        replacement parts immediately on hand........... 4

    b. Inadequate space................................. 3

    c. Test equipment-tools and/or replacement parts
        not immediately on hand.......................... 1

    d. Combination of B and C........................... 0

OPERATION

16. <u>Area</u>

    a. Equipment and accessories completely accessible
        from all sides of via slide-out drawers, chassis,
        etc............................ 4

    b. Partly accessible................................ 2

    c. Not accessible................................... 0

17. <u>Power</u>

    a. Power source is capable of supplying equipment
        with sufficient power at proper voltage and
        frequency.. 4

    b. Deviation approaches equipment limits............ 2

    c. Power source inadequate.......................... 0

18. <u>Installation</u>

    a. Equipment has been installed in an orderly manner. Cables have been properly tailored, thus facilitating maintenance action............ 4

    b. Some maintenance time can be attributed to poor installation.................................. 2

    c. Installation is very poor, resulting in increased maintenance time................................. 0

ENVIRONMENTAL CONDITIONS

19. <u>Equipment Environment</u>

    a. Air conditioning or ventilation is adequate and temperature is kept within specified limits...... 4

    b. Air conditioning or ventilation not adequate..... 0

20. <u>Equipment Housing</u>

    a. All components of the equipment are located within a shelter.................................. 4

    b. Some portions are not provided shelter........... 2

    c. No protection is provided....................... 0

WORKING CONDITIONS

21. <u>Hazardousness</u>

    a. Personnel are required to perform few hazardous
        or difficult tasks............................. 4

    b. Personnel are required to perform many hazardous
        tasks.. 0

                                                    _____

22. <u>Work Load</u>

    a. Personnel work a normal 40 hour week............ 4

    b. Personnel work in excess of 40 hours per week.... 2

    c. Personnel work shift work on a rotating basis.... 1

                                                    _____

23. <u>Working Area</u>

    a. Working area is adequately lighted, large enough
        and properly ventilated........................ 4

    b. Working area is inadequately lighted............ 3

    c. Working area is not large enough................ 3

    d. Working area is not properly ventilated......... 2

    e. Any two-combination of items 2, 3 and 4......... 1

    f. Combination of 2, 3 and 4....................... 0

                                                    _____

24. <u>Tools and Equipment Status</u>

    a.   All test equipment and tools as authorized by
         AF Manual 67-1 are on account..................... 4

    b.   Equipment in excess of manual requirements....... 3

    c.   Most on hand balance on order via UAL in
         accordance with AFR 67-83 and AFR 67-92.......... 2

    d.   Needed equipment not on hand and no action has
         been taken to obtain............................. 0

APPENDIX II

MATHEMATICAL FORMULAS

APPENDIX II

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APPENDIX II

MATHEMATICAL FORMULAS

1. INTRODUCTION

This appendix presents the formulas and terms used in the derivation of the regression equation.

2. DEFINITIONS

M_{ct} = Active Down Time (minutes)

T_{ct} = Active Technician Time (minutes)

Z = Log M_{ct}

Y = Log T_{ct}

N = Number of entries in a column.

A = Physical Design Factors

B = Design Dictates - Facilities

C = Design Dictates - Maintenance Skills (Physical, Mental, and Attitudinal Requirements)

E = Manuals, Technical Orders, and Instructions

F = Supply Conditions

G = Test Equipment and Tools

H = Maintenance Organization and Facility Status

S = $E + F + G + H$ = Support

$S_x = \sum_{i=1}^{N} X_i$ = Sum of entries in column X

$\bar{S}_x = \bar{X} = \sum_{i=1}^{N} X_i /N$ = Mean of the entries of column X.

$$SS_x = \sum_{i=1}^{N} X_i^2 \quad = \text{Sum of the squares of entries in column } X$$

$$SSD_x = SS_x - S_x^2/N = \sum_{i=1}^{N} (X_i - \bar{X})^2 = \text{Sum of squares of the deviations from the mean.}$$

$$\sigma_x^2 = SSD_x/(N-1) = \text{Variance of } X$$

$$\sigma_x = \sqrt{SSD_x/(N-1)} = \text{Standard Deviation of } X$$

$$c_x = \sigma_x / \bar{S}_x = \text{Coefficient of Variation of } X$$

$$SP_{xw} = \sum_{i=1}^{N} (X_i \, W_i) = \text{Sum of the products of the entries in two columns}$$

$$SPD_{xw} = SP_{xw} - S_x S_w /N = \sum_{i=1}^{N} (X_i - \bar{X})(W_i - \bar{W}) = \text{Sum of the products of the deviations.}$$

$$s_{xw} = SPD_{xw}/(N-1) = \text{Convariance of } X \text{ and } W$$

$$r_{xw} = s_{xw}/(\sigma_x \sigma_w) = SPD_{xw} / \sqrt{(SSD_x)(SSD_w)} = \text{Simple correlation coefficient relating } X \text{ to } W$$

$$b = SPD_{xw}/SSD_x = \text{Simple regression coefficient relating } X, \text{ the independent variable, to } W, \text{ the dependent variable.}$$

3. PROOF OF NORMALITY

The Komolgorov-Smirnov (d) test, a non-parametric test for goodness of fit (4,11) with the theoretical normal distribution, was applied to all of the variables including Z. Each passed it successfully at the 95% level. Table II-1, "Test for Normality of Checklist B," is presented as an example of the calculations. The upper and lower bounds are computed by the formula:

$$d_{(.95)} = 1.36/\sqrt{N} \qquad N > 30 \qquad \text{(II-1)}$$

Figure II-1, "Comparison of Cumulative Observed Scores (Checklist B) with Cumulative Normal Distribution," used the data from Table II-1 to make a graphical comparison (d =.136). If the observed distribution should have cut either the lower or upper boundary around the normal distribution. However, it did not, indicating that Checklist B was normally distributed. In carrying out the test on Figure II-1, probability paper was used for convenience, because the cumulative normal curve is a straight line on this paper. In testing the time measurements, first M_{ct} was tested in the real time form and, when it was not successful in passing the test at 95% level, it was converted to the log form. They were a good fit, to the theoretical log normal distribution, in the form log M_{ct}.

4. CORRELATION ANALYSIS

A major requirement of a linear regression equation is that the variables are independent. This may be shown by submitting the correlation coefficients to a partial correlation analysis. Table II-2, "Sample Correlation Analysis, shows a typical DOLITTLE Solution employing the GAUSS multipliers. For the most part, the method employed by HALD [6] was used. For the final calculation of the partial r's, the method employed by GOULDEN [7] was used. The Dolittle method is a systematic progression of operations leading to the solution of linear equations.

TABLE II-1

TEST FOR NORMALITY OF CHECKLIST B

Observed				Theoretical		$d_{(.95)} = .135$	
Check-list	Freq.	Cum. Freq.	Cum. Prob.	$(B_1-\bar{B})/\sigma_b$	Cum. Prob.	Lower Bound	Upper Bound
B	f	c.f.	c.p.	z	c.p.	L.B.	U.B.
9	2	2	.020	−2.53	.006	0	.141
10	1	3	.030	−2.32	.010	0	.145
11	3	6	.059	−2.10	.018	0	.153
14	2	8	.079	−1.45	.074	0	.209
15	5	13	.129	−1.23	.109	0	.244
16	7	20	.198	−1.02	.154	.019	.289
17	3	23	.228	− .80	.212	.077	.347
18	7	30	.297	− .59	.278	.143	.413
19	5	35	.347	− .39	.356	.221	.491
20	17	52	.515	− .15	.440	.305	.575
21	2	54	.535	.06	.524	.389	.659
22	11	65	.644	.28	.610	.487	.745
23	2	67	.663	.50	.692	.557	.827
24	10	77	.762	.71	.761	.626	.896
25	5	82	.812	.93	.824	.689	.959
26	12	94	.931	1.15	.875	.740	1
28	7	101	1.000	1.58	.942	.807	1
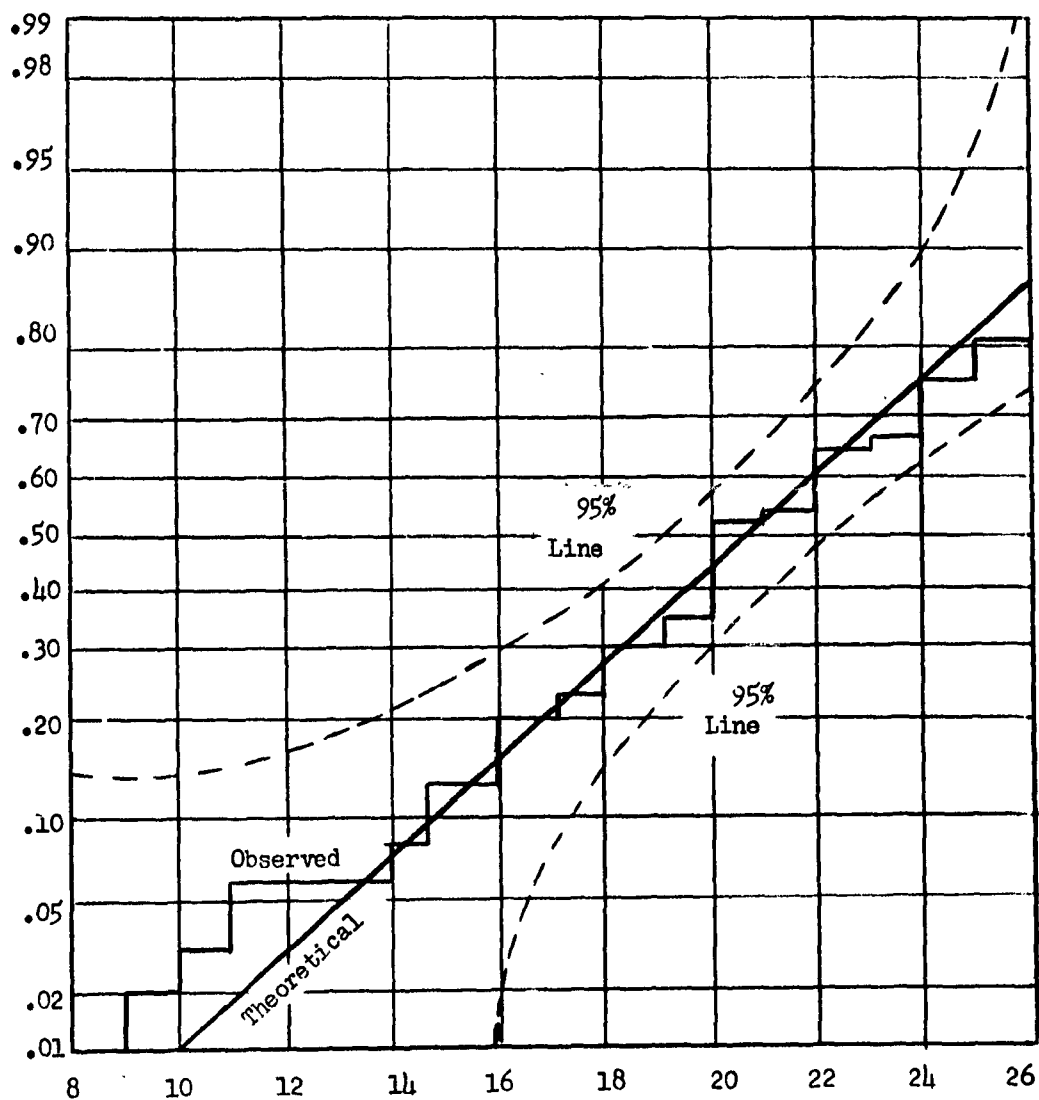
FIGURE II-I   COMPARISON OF CUMULATIVE OBSERVED SCORES
               (CHECKLIST B) WITH CUMULATIVE NORMAL
               DISTRIBUTION

TABLE II-2
SAMPLE CORRELATION ANALYSIS

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No.	Operation	x_1	x_2	x_3	c_1	c_2	c_3	Instructions for Carrying Out the Analysis
1	x_1	r_{11}	r_{12}	r_{13}	1	0	0	Line 1 to 3 enter known values of simple
2	x_2		r_{22}	r_{23}		1	0	correlation coefficients (r_{ij}) and the
3	x_3			r_{33}				Gaussian multipliers (c_{ij})
4	$1 \times -r_{12}/r_{11}$		$-r_{12}/r_{11}$	$-r_{12}r_{13}/r_{11}$	$-r_{12}/r_{11}$	0	0	Line 4 to 8 perform the indicated operation
5	$4 + 2$		$r_{22.1}$	$r_{23.1}$	$-r_{12}/r_{11}$	1	0	
6	$1 \times -r_{13}/r_{11}$			$-r_{13}/r_{11}$	$-r_{13}/r_{11}$	0	0	
7	$5 \times -r_{23.1}/r_{22.1}$			$-r_{23.1}/r_{22.1}$	$(r_{23.1})(r_{12})/(r_{22.1})(r_{11})$	$-r_{23.1}/r_{22.1}$	0	Check: $b_1 r_{11} + b_2 r_{12} = r_{13}$
8	$7 + 6 + 3$			$r_{33.12}$	$-b_1$	$-b_2$	1	Also: $b_1 r_{12} + b_2 r_{22} = r_{23}$
b_1		b_1	b_2					
9	$8 \times 1/r_{33.12}$				c'_{31}	c'_{32}	c'_{33}	Line 9: $c'_{31} = -b_1/r_{33.12} = c'_{13}$
10	Substitute in Line 5				c'_{21}	c'_{22}	c'_{23}	Line 10: $c'_{21} = (-r_{12}/r_{11}) - (c'_{31} r_{23.1})/r_{22.1} = c'_{12}$ etc.
11	Substitute in Line 1				c'_{11}	c'_{12}	c'_{13}	Line 11: $c'_{11} = 1-(c'_{31} r_{13}) - (c'_{21} r_{12})$, etc.
12		b'_{31}	b'_{32}		$r'_{31.2}$	$r'_{32.1}$		Line 12: $r'_{31.2} = c'_{31}/\sqrt{c'_{11}c'_{33}} = r'_{13.2}$
13		b'_{21}		b'_{23}	$r'_{21.3}$			$r'_{31.1} = c'_{31}/\sqrt{c'_{22}c'_{33}} = r'_{23.1}$
14			b'_{12}	b'_{13}				Line 13: $r'_{21.3} = c'_{21}/\sqrt{c'_{11}c'_{22}} = r'_{12.3}$
	Return to Line 12 and calculate b'_{1i}; $b'_3 = -c'_{31}/c'_{33}$, $b_{11} = c'_{13}/c'_{13}$, etc.							A complete check is made by computing r'_{11} from b'_{11}
15	Calculate multiple r	$r_{33.12} = 1-r^2_{23.12}$	$r_{3.12} = \sqrt{1-r^2_{33.12}}$ = multiple correlation coefficient					and b'_{ji} as follows: $r'_{31.2} = \sqrt{b'_{13} b'_{31}}$, etc.

5. REGRESSION ANALYSIS

The regression analysis follows the same procedure outlined in 4.0 for the correlation analysis. However, instead of using the simple correlation coefficients for the b's, the SSD's and SPD's were used: e.g.

	$\underline{b}_a$	$\underline{b}_b$	$\underline{b}_c$	$\underline{b}_z$
A	SSD_a	SPD_{ab}	SPD_{ac}	SPD_{az}
B		SSD_b	SPD_{bc}	SPD_{bz}
C			SSD_c	SPD_{cz}
D				SSD_z

The Gaussian multipliers are one.

6. MANN-WHITNEY U TEST

6.1 General

The Mann-Whitney test is used to test whether two independent samples have been drawn from the same population. It is one of the most powerful of the nonparametric tests. It is a useful alternative to the parametric t test when one wishes to avoid the parametric assumptions of t test. The discussion will be limited to the case of N_1 greater than 20.

6.2 Procedure

In applying the U test the first step is to combine the observations from the two groups. Then rank them in order of increasing size. (See Table II-3, "Sample Ranking for Mann-Whitney Test-AN/FPS-6.") Add the ranks of smaller sample (N_1) and call it R_1. Then compute the value of U by the following equation:

TABLE II-3

SAMPLE RANKING FOR MANN-WHITNEY TEST-AN/FPS-6

Observed (n_1)		Predicted (n_2)			
M_{ct}	Rank	M_{ct}	Rank	M_{ct}	Rank
2.7	1	12.8	3	47.0	32
3.4	2	19.7	4	47.7	33
20.0	5	23.3	6	48.1	34
25.5	7	26.4	8	49.4	35
27.0	9	30.2	11	52.2	37
28.9	10	32.1	12	52.7	38
51.1	36	34.3	13	54.6	39.5
56.9	43	34.8	14	54.6	39.5
59.2	44	35.1	15	54.8	41
59.5	45	36.1	16	54.9	42
62.8	47	36.5	17	62.7	46
84.4	52	37.5	18	63.2	48
99.2	56	37.8	19	69.9	49
114.7	58	38.1	20	80.3	50
116.6	59	38.8	21	83.1	51
139.0	62	39.7	22	87.4	53
156.9	64	40.1	23.5	92.4	54.5
166.2	65	40.1	23.5	92.4	54.5
174.1	67	41.4	25	110.2	57
188.7	69	43.6	26.5	124.6	60
207.2	70	43.6	26.5	125.6	61
224.7	71	44.2	28	142.3	63
		44.5	29	170.3	66
		45.8	30	181.2	68
		46.9	31	448.0	72

$R_1 = 942$

$$U = n_1\, n_2 + \frac{n_1\,(n_1 + 1)}{2} - R_1 \qquad \text{(II-2)}$$

6.3 Method of Testing Significance

As n_1, n_2 increase in size the sampling distribution of U rapidly approaches the normal distribution with

$$\mu_u = \frac{n_1\, n_2}{2} \quad \text{(Mean)} \qquad \text{(II-3)}$$

and

$$\sigma_u = \sqrt{\frac{(n_1)\,(n_2)\,(n_1 + n_2 + 1)}{12}}$$

$$\text{(Standard Deviation) (II-4)}$$

Therefore, when n_1 is greater than 20, significance of an observed U can be determined by

$$z = \frac{U - \mu_u}{\sigma_u} \qquad \text{(II-5)}$$

Which is normally distributed with a mean of 0 and a standard deviation of 1. The null hypothesis states that there is no difference between the two samples. Testing at the 5% level this would mean the Z would have a value of 1.96 (two tail test) or greater to be significant.

7. Contingency Coefficient

To compute the contingency coefficient between scores on two sets of categories, say A_1, A_2 ..., A_k, and B_1, B_2, ... B_r, arrange the frequencies, O (A_k, B_r) as illustrated in Table II-4, "Contingency Table." The frequencies that would be expected if there were no association between the variables are entered in each cell as E (A_k, B_r), X^2 is then computed for the table using the formula:

$$X^2 = \sum_{j=1}^{r} \sum_{i=1}^{k} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \qquad \text{(II-6)}$$

TABLE II-4

CONTINGENCY TABLE

	A_1	A_2	$\cdots$	A_k	Total
B_1	$E(A_1,B_1)$ $O(A_1,B_1)$	$E(A_2,B_1)$ $O(A_2,B_1)$	$\cdots$	$E(A_k,B_1)$ $O(A_k,B_1)$	$\sum\limits_{i=1}^{k} O_{i1}$
B_2	$E(A_1,B_2)$ $O(A_1,B_2)$	$E(A_2,B_2)$ $O(A_2,B_2)$	$\cdots$	$E(A_k,B_2)$ $O(A_k,B_2)$	$\sum\limits_{i=1}^{k} O_{i2}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
B_r	$E(A_1,B_r)$ $O(A_1,B_r)$	$E(A_2,B_r)$ $O(A_2,B_r)$	$\cdots$	$E(A_k,B_r)$ $O(A_k,B_r)$	$\sum\limits_{i=1}^{k} O_{ir}$
Total	$\sum\limits_{j=1}^{r} O_{ij}$	$\sum\limits_{j=1}^{r} O_{2j}$	$\cdots$	$\sum\limits_{j=1}^{r} O_{kj}$	N

Where: O_{ij} = Observed number of cases in ith row of jth column

E_{ij} = Expected number of cases in ith row of jth column

The coefficient of contingency is then calculated using the formula:

$$C = \sqrt{\frac{X^2}{N + X^2}}$$ (II-7)

The significance of the coefficient may be tested by determining whether the X^2 of the data is significant for degrees of freedom $(k - 1)(r - 1)$.

APPENDIX III

MAINTENANCE DATA FORMS

APPENDIX III

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APPENDIX III

MAINTENANCE DATA FORMS

1. INTRODUCTION

This appendix contains the forms used to gather field and laboratory data, along with the forms used for the design prediction of maintainability. These forms are listed as follows:

    a. Maintenance Task Score Sheet
    b. Checklist H Maintenance Organization Score Sheet
    c. Task Time Study Sheet
    d. Maintenance Task Time Measurement Sheet
    e. Maintenance Task Time Measurement Continuation Sheet
    f. Biographical Data Sheet
    g. Maintainability Prediction Form
    h. Maintenance Analysis Continuation Sheet

Use of these forms are described in subsequent paragraphs.

2. MAINTENANCE TASK SCORE SHEET

2.1 This form, Table III-1, is used for recording the scores obtained from completing the design and support checklists which include the following individual checklists:

    a. Design

        1. Checklist A - Physical Design
        2. Checklist B - Design Dictates - Facilities
        3. Checklist C - Design Dictates - Maintenance Skills

    b. Support

        1. Checklist E - Scoring Manuals, Technical Orders, and Instructions
        2. Checklist F - Scoring Supply Conditions
        3. Checklist G - Scoring Test Equipment and Tests

2.2 The three design checklists A, B, and C and support checklists E, F, and G are scored for each maintenance task observed. The checklists and scoring criteria are described in Appendix I.

2.3 Items, 1 thru 6 inclusive appear on this and several
other checklists in Appendix I. These six items are
described in detail for the Maintenance Task Score Sheet
and are similarly applicable whenever they appear on other
forms:

    a. <u>Site No.</u> - A numerical code assigned for the geo-
        graphic location of the equipment.

    b. <u>Equipment</u> The nomenclature of the system or unit
        under observation.

    c. <u>Task No.</u> One of a consecutive series of numbers
        assigned to each equipment.

    d. <u>Down Time</u> This is the total time that the equip-
        ment is unavailable for operational use due to a
        maintenance action.

    e. <u>Observer</u> The signature of the observer is re-
        quired.

    f. <u>RCA Code</u> Each technician has a code designator as
        follows:

        1. Digits No. 1 and No. 2 = Site number (51, 52
            53, etc.)

        2. Digit No. 3 = Type equipment on which the
            technician has the most experience.

        3. Digit No. 4 = AFSC Level (3, 5, or 7.)

        4. Digits No. 5 and 6 = Assigned number for each
            technician in the equipment section or sections.

            Example: John Jones   01
                            Bill Brown   02
                            Joe Black   03

2.4 The Remarks column is used as required to record special
information pertaining to particular question scores.

3. CHECKLIST H - MAINTENANCE ORGANIZATION SCORE SHEET

3.1 This form, Table III-2, is used to record scores obtained when completing checklist H Maintenance Organization, which was presented in Appendix I. The checklist is designed to measure the effect of support factors on a maintenance task. The basic information, common to these forms, appears at the top of the form. Then follow provisions for 24 scores, as described in Appendix I, covering such items as supervisory level rating, work schedule, working conditions, and the adequacy of support facilities.

4. TASK TIME STUDY SHEET

4.1 This form, Table III-3, is used to record the elapsed times for, and descriptions of, each maintenance action as the maintenance proceeds. The identity of the technician performing each action is also noted. These data are for summary subsequently transferred to the Maintenance Task Time Measurement Sheet (Table III-4.)

5. MAINTENANCE TASK TIME MEASUREMENT SHEET

5.1 On this form, Table III-4, are recorded the eight time elements associated with a particular maintenance task. The form is designed for the recording of time data associated with each task element by the individual technicians (technician time) and the total time required to accomplish the task, as factors of down time. The task time format is completed after the task has been accomplished from data recorded on the Task Time Study Sheet.

5.2 Item Description

The following items and elements are observed and recorded on the form:

    a. Items 1 through 6 These are the same as items described above in paragraph 2.3.

    b. Element Identity The number (1 through 8) of the particular time element completed by a technician.

c. Elapsed Time The time recording device (stop watch)
    is started at zero time. As each technician com-
    pletes a maintenance element, the time of completion
    is noted here as accumulated time.

d. Number of Operations The number of steps required to
    complete a task.

e. Technician Identity Alphabetic letters corresponding
    to the RCA Code of identity as described in para-
    graph 2.3, f, 4, are entered here.

f. Elements 1 through 8 Actual time a technician re-
    quired to accomplish an element is recorded. For a
    particular technician this is the accumulated time
    indicated at the completion of the previous element.

g. Active Technician Time The summation of the 1
    through 6 element times for each technician.

h. Delay Technician Time The summation of the 7 and
    8 element times for each technician.

i. Total Technician Time The sum of active technician
    time and delay technician time.

j. Active Down Time The total time required to com-
    plete elements 1 through 6 as indicated by the
    stop watch.

k. Delay Down Time The time spent by all technicians
    on elements 7 and 8.

l. Total Time The elapsed time recorded on the stop
    watch on completion of the maintenance task.

6. MAINTENANCE TASK TIME MEASUREMENT CONTINUATION SHEET

6.1 This form, Table III-5, is used to summarize, in
narrative form, the data recorded on the Maintenance Task
Time Sheet. These data include a thorough description of,
(1) symptoms observed, (2) the cause of the failure and
(3) the corrective actions taken to restore the equipment
to normal operation.

6.2 Item Description

a. **Items 1 through 6** include the data common to this family of report forms.

b. **Items 7 through 11** are in the main self-explanatory. The data for these items are obtained from the Task Time Study Sheet (Table III-3.)

c. **Item 12** Symptoms reported and summarized here are the equipment failure symptoms.

d. **Items 13 through 16** Here are related the cause of the failure, including a brief relation to the processes used to determine the cause; the remedy made to restore normal operation; and the part(s) used in effecting a restoration of normal operation. All actions pursued, even erroneous steps taken during malfunction analysis and correction, are to be included in the summarization.

7. BIOGRAPHICAL DATA SHEET

The biographical data sheet, Table III-6, provides background information on each technician observed, including civilian contractor personnel.

8. MAINTAINABILITY PREDICTION FORM

8.1 This form, Table III-7, is used to record the information necessary for predicting down time for each selected task, and the data derived from this prediction. Space is provided on this form for performing a maintenance analysis. If the space is insufficient, the Maintenance Analysis Continuation Sheet described in Section 9 below is used.

8.2 Item Description

a. **Equipment** The nomenclature and/or type identity of the equipment being analyzed.

b. **Unit/Part** The name and/or circuit identity of the failed part which caused the maintenance action.

c. **Task Number** A number is assigned to each task.

d. <u>Assembly</u> The section or identity of the equipment in which the failed part is located; e.g., power supply, audio section, etc.

e. <u>By</u> The name of the individual scoring the prediction.

f. <u>Date</u> Day, month, and year prediction was scored.

g. <u>Primary function failed unit/part</u> This is a description of the function of the assumed failed unit/part.

h. <u>Mode of failure</u> This describes how the unit/part failed; e.g., shorted, open, cracked, etc.

i. <u>Malfunction symptoms</u> This is a short description of the outward indications of the failed unit or part; e.g., oscillates, low gain, no output, etc.

j. <u>Maintenance Analysis</u> This is a two phase procedure involving (1) Maintenance Steps, and (2) Scoring Comments describing observations associated with the maintenance procedure.

k. <u>Checklist Scores</u> From the Design Checklists, A, B, and C, the numerics corresponding to the comments describing the step conditions are obtained and entered into the respective boxes. These scores are then totalled.

l. <u>Predicted down time - Minutes</u> The down time derived from the prediction equation is entered here.

9. MAINTENANCE ANALYSIS CONTINUATION SHEET

9.1 This form, Table III-8, is provided for the continuation of the analysis from the maintainability prediction form. Continuity is established by listing 8a, b, and c. Then space on the sheet is provided for an extensive maintenance analysis (8j.)

TABLE III-1

MAINTENANCE TASK SCORE SHEET

1. Site No:	2. Equipment:	3. Task No:	4. Down Time (hrs. & mins.):	5. Observer:
6. RCA Code:	A:	B:	C:	D:

DESIGN PARAMETERS

Sub Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Remarks
A-Physical Design Factors																	
B-Design Dictates - Facilities																	
C-Design Dictates - Maintenance Skills																	

SUPPORT PARAMETERS

E-Manuals, T.O.'s, & Instructions																	
F-Supply Conditions																	
G-Tools & Test Equipment																	

TABLE III-2
CHECKLIST H MAINTENANCE ORGANIZATION SCORE SHEET

Date:_____   Organization:_____

Site No:_____   Observer:_____

Location:_____   NCOIC RANK:_____

1._____   7._____   13._____   19._____

2._____   8._____   14._____   20._____

3._____   9._____   15._____   21._____

4._____   10._____   16._____   22._____

5._____   11._____   17._____   23._____

6._____   12._____   18._____   24._____

Total

COMMENTARY:

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

TABLE III-3

TASK TIME STUDY SHEET

SITE NO:_____ EQUIP._____ TASK NO._____

Tech.	Elap. Time	COMMENTS

TABLE III-4

MAINTENANCE TASK TIME MEASUREMENT SHEET

1. Site No.:	2. Equipment:	3. Task No.:	4. Down Time (Hrs. & Min.)	5. Observer
6. RCA Code No. :	A:	B:	C:	D:	Sheet___ of___

Element Identity	Elapsed Time	No. Operations	Technician Identity	Assembly-Disassembly	Inspection, Testing, Measuring	Remove & Replacement	Check-out	Cleaning and Lubrication	Securing Materials	Preparation of Reports	Contingency Items	Active Tech. Time	Delay Tech. Time	Total Tech. Time	Active Down Time	Delay Down Time	Total Time
			1	2	3	4	5	6	7	8						
1																	
2																	
3																	
4																	
5																	
6																	
7																	
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21																	
22																	
23																	
24																	

TABLE III-5

MAINTENANCE TASK TIME MEASUREMENT CONTINUATION SHEET

1. Site No.:	2. Equipment:	3. Task No.:	4. Down Time:	5. Observer	6. RCA Code No.:
7. Task Duration		8. Tot. Tech. Time	9. Tot. Down Time	10. Type of Maint	11. No. Sheet
Start Mon__Da__Time__	Finish Mon__Da__Time__	Min. Hr.	Min. Hr.	C.M. P.M.	____ of ____

12. Symptoms

13. Cause of Trouble

14. Trouble-Shooting Procedure

15. Remedy

16. Replacements

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TABLE III-6

BIOGRAPHICAL DATA SHEET

1. Name_____ RCA Code_____

2. Service No._____ 3. Pay Grade_____

4. Age_____ 5. Years in Service_____

6. Date of last Enlistment_____

7. Site Location_____ 8. Date Arrived_____

9. Service School

       Course_____   Date Grad._____

       _____   _____

       _____   _____

10. Maintenance Experience

       Equipment_____   Time_____

       _____   _____

       _____   _____

       _____   _____

11. Civilian School (Circle highest level completed)

    Grade School 1 2 3 4 5 6 7 8 9 10 11 12

    High School 1 2 3 4

    College   1 2 3 4   Degree_____

    Major Fields_____   _____

    Others_____

12. Civilian Experience
    Type of Work and/or Schools   Time

    _____   _____

    _____   _____

    _____   _____

    _____   _____

TABLE III-7

MAINTAINABILITY PREDICTION FORM

Equip._____   Unit/Part _____   Task No._____

Ass'y._____   By_____   Date_____

Primary function failed unit/part_____

_____

Mode of failure_____

Malfunction symptoms_____

_____

Maintenance Analysis

Maintenance Steps	Scoring Comments

Checklist Scores

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
A																
B																
C																

Predicted down time. . . . . _____Min.

TABLE III-8

MAINTENANCE ANALYSIS CONTINUATION SHEET	
Equip._____ Part_____ Task No._____	
Maintenance Steps	Scoring Comments

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